# Department of Energy
Washington, DC 20545

SEP 0 1 1993



Mr. Gerry A. Harvey, Director
Operations Support Services
Westinghouse Hanford Company
Post Office Box 1970
Richland, Washington 99352

Dear Mr. Harvey:

This Hazard and Operability Study (HAZOP) of the 300 Area Water Treatment Facility Chlorination System is a result of successful teamwork among the Department of Energy (DOE), Westinghouse Hanford Company (WHC), and Battelle staff members and demonstrates the use and application of a major process hazards analysis (PrHA) technique. The PrHA will support WHC chemical safety activities and provide a useful example for all DOE contractors.

In response to the requirements of the Process Safety Management of Highly Hazardous Chemicals (PSM) Rule (29 CFR 1910.119), DOE's Office of Safety and Quality Assurance established a PSM Program that provides guidance, training, and support to assist DOE contractors in their efforts to comply with the rule. As PrHA is considered a critical element of the rule, a demonstration analysis was planned as part of the program's 1993 work. When WHC operations personnel suggested an analysis be done of the 300 Area Water Treatment Facility Chlorination System, it seemed ideal for the demonstration. Chlorine is the most common chemical at DOE sites that is regulated under the PSM Rule and thus a demonstration analysis of a chlorination system would have wide applicability across DOE. The HAZOP technique was selected as it was judged appropriate to the complexity of the system and would effectively identify and evaluate the system's hazards.

This study is not only an example of a PrHA that we believe complies with the PSM Rule, but also demonstrates a structured, brainstorming technique that is a practical and effective management tool for the identification and control of hazards of any process. I would like to express my appreciation for the support of the WHC personnel whose participation made this study a success.

Sincerely,

Joseph E. Fitzgerald

Joseph E. Fitzgerald, Jr.
Deputy Assistant Secretary
Safety and Quality Assurance

DOE/EH-0340

# EXAMPLE PROCESS HAZARD ANALYSIS OF A DEPARTMENT OF ENERGY WATER CHLORINATION PROCESS

September 1993

U.S. Department of Energy
**Assistant Secretary for Environment, Safety and Health**
**Office of Deputy Assistant Secretary for Safety and Quality Assurance**
**Washington, DC 20585**

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## TABLE OF CONTENTS

## LIST OF TABLES



## LIST OF FIGURES

## LIST OF ACRONYMS

| | |
|---|---|
| AIChE | American Institute of Chemical Engineers |
| BLEVE | boiling liquid expanding vapor explosion |
| CFR | Code of Federal Regulations |
| DOE | U.S. Department of Energy |
| HHC | highly hazardous chemical |
| HAZMAT | hazardous materials |
| HAZOP | hazard and operability |
| IDLH | immediately dangerous to life or health |
| MSDS | Material Safety Data Sheet |
| ORPS | Occurrence Reporting and Processing System |
| OSHA | Occupational Safety and Health Administration |
| PrHA | process hazard analysis |
| PNL | Pacific Northwest Laboratory |
| ppm | part per million |
| PSM | process safety management |
| SCBA | self-contained breathing apparatus |
| TQ | threshold quantity |
| WAC | Washington State Administrative Code |
| WHC | Westinghouse Hanford Company |

# EXAMPLE PROCESS HAZARD ANALYSIS OF A DEPARTMENT OF ENERGY WATER CHLORINATION PROCESS

## 1.0 INTRODUCTION

On February 24, 1992, the Occupational Safety and Health Administration (OSHA) released a revised version of Section 29 Code of Federal Regulations (CFR) Part 1910 that added Section 1910.119, entitled "Process Safety Management of Highly Hazardous Chemicals" (the PSM Rule). Because U.S. Department of Energy (DOE) Orders 5480.4 and 5483. 1A prescribe OSHA 29 CFR 1910 as a standard in DOE, the PSM Rule is mandatory in the DOE complex.

A major element in the PSM Rule is the process hazard analysis (PrHA), which is required for all chemical processes covered by the PSM Rule. The PrHA element of the PSM Rule requires the selection and application of appropriate hazard analysis methods to systematically identify hazards and potential accident scenarios associated with processes involving highly hazardous chemicals (HHCs).

The analysis in this report is an example PrHA performed to meet the requirements of the PSM Rule. The PrHA method used in this example is the hazard and operability (HAZOP) study, and the process studied is the new Hanford 300-Area Water Treatment Facility chlorination process, which is currently in the design stage. The HAZOP study was conducted on May 18-21, 1993, by a team from the Westinghouse Hanford Company (WHC), Battelle-Columbus, the DOE, and Pacific Northwest Laboratory (PNL). The chlorination process was chosen as the example process because it is common to many DOE sites, and because quantities of chlorine at those sites generally exceed the OSHA threshold quantities (TQs).

The report is organized into 13 sections and 5 appendices. Section 2.0 summarizes the requirements of the PSM Rule for performing PrHAs. Section 3.0 describes the scope and assumptions used in the analysis. Section 4.0 presents a list of recommendations and action items developed during the HAZOP study. Section 5.0 is an overview of the Hanford 300-Area Water Treatment Facility chlorination process, including process diagrams.

Section 6.0 contains brief descriptions of previous incidents at the Hanford 300-Area Water Treatment Facility involving the old chlorination process, and Section 7.0 summarizes the hazards of chlorine. Section 8.0 describes the HAZOP study method, and Section 9.0 lists the HAZOP team members and their roles.

Section 10.0 describes the location of the Hanford 300-Area Water Treatment Facility in relation to the public and to employees. Section 11.0 presents a brief discussion of the possible causes of human errors identified during the HAZOP study. The HAZOP summary is presented in Section 12.0, and Section 13.0 contains the study references.

Appendix A of this report contains the procedure for change-out of chlorine cylinders. The HAZOP study worksheets are provided in Appendix B. The effects of chlorine releases are estimated in Appendix C. Appendix D contains a Material Safety Data Sheet for chlorine. Appendix E presents the resumes of the HAZOP study team members.

## 2.0 SCOPE OF ANALYSIS

This report illustrates the use of the process hazard analysis (PrHA) required by the Occupational Safety and Health Administration (OSHA) rule 29 CFR 1910.119, "Process Safety Management of Highly Hazardous Chemicals" (the PSM Rule). The Hanford 300-Area Water Treatment Facility chlorination process was selected for analysis because it is a process common to many U.S. Department of Energy (DOE) sites, and quantities of chlorine at those sites generally exceed the OSHA threshold quantities (TQs). The analysis method selected was the hazard and operability (HAZOP) study.

The HAZOP study was performed on the new chlorination process design at the Hanford 300-Area Water Treatment Facility. At the time of the study, the new system was partially installed but not operating. The HAZOP study consisted of four full-day sessions and covered both the chlorination process and the procedures for change-out of chlorine cylinders. The worksheets in Appendix B document the HAZOP study.

The study assumed that the chlorination process was essential and that questions regarding elimination or replacement of chlorine with other types of disinfection technologies were outside of scope. Although a separate seismic analysis was not performed, seismic failures were considered similar to existing HAZOP study scenarios (e.g., line, valve, and cylinder failures).

Additional information regarding the PSM Rule and the performance of PrHAs is available in the *DOE Guideline: Preliminary Guide for Conformance with OSHA's Rule for Process Safety Management of Highly Hazardous Chemicals* (Draft, DOE/EH, March 1993), and the *DOE Guideline: Guide for Chemical Process Hazard Analysis* (Draft, DOE/EH, March 1993).

# 3.0 PROCESS HAZARD ANALYSIS REQUIREMENTS

This section provides a general overview of the process safety management (PSM) requirements and objectives for conducting process hazard analyses (PrHAs) under the Occupational Safety and Health Administration (OSHA) rule 29 CFR 1910.119, the PSM Rule. This section would not normally be included in a PrHA. Rather, in its place would be a section discussing the specific objectives that management wished to accomplish in the PrHA.

## 3.1 Objectives

The objective of the PSM rule is to protect employees by preventing or minimizing the consequences and impacts of chemical accidents involving highly hazardous chemicals (HHCs). This objective is partly fulfilled by performance of PrHAs to identify hazards and recommend safety improvements in the design and operation of chemical processes. The scope and level of detail of a PrHA must be appropriate to the complexity of the chemical process being evaluated. A PrHA should

- Identify the hazards of a process
- Evaluate previous process incidents that had the potential to cause catastrophic consequences or impacts in the workplace
- Evaluate the engineering and/or administrative controls applicable to the process hazards and their interrelationships (e.g., detection methods for releases)
- Identify the consequences of failure of engineering and/or administrative controls
- Review facility siting issues
- Evaluate the importance of human factors on the likelihood and/or consequences of process accidents
- Evaluate qualitatively the range of possible safety and health effects on employees from failure of engineering and/or administrative controls
- Identify procedural or process safety improvements to better control process hazards.

## 3.2 Review Team

The PSM Rule requires that a PrHA be conducted by a team consisting of the following individuals:

- At least one member with expertise in engineering and process operations

- At least one member with experience and knowledge specific to the process being evaluated

- A team leader knowledgeable in the specific PrHA methodology being used.

## 3.3 Schedule

If facilities have more than one process covered by the PSM Rule, facility management must determine and document the priority order for conducting PrHAs for all the covered processes. The order for completing PrHAs should be based on a rationale that includes such considerations as

- The extent of the process hazard
- The number of potentially affected employees
- The age of the process
- The operating history of the process.

PrHAs for processes covered by the PSM Rule must be completed according to the following schedule:

- No less than 25 percent by May 26, 1994
- No less than 50 percent by May 26, 1995
- No less than 75 percent by May 26, 1996
- All of the initial PrHAs (100 percent) by May 26, 1997.

PrHAs completed after May 26, 1987, that meet the requirements of the PSM Rule are acceptable as initial PrHAs. They must be updated and revalidated in accordance with the PSM Rule requirements.

## 3.4 Methodology

The PrHA element of the PSM Rule requires the selection and application of appropriate hazard analysis methods to systematically identify hazards and related accident scenarios associated with highly hazardous chemicals. Although the PSM Rule allows the use of several different methods, it requires that the selection of a particular method be based on consideration of the process being analyzed. One or more of the following methods, or an appropriate equivalent method, must be used: what-if study, checklist, what-if/checklist, HAZOP study, failure mode and effects analysis, and/or fault tree analysis.

### 3.5 Recommendations and Updates

The resolution of PrHA findings and recommendations are not part of a PrHA, *per se*. However, an employer must establish a system to promptly address a PrHA team's findings and recommendations. A schedule for resolutions must be established to assure that all recommendations are resolved and documented. All actions taken as a result of PrHA findings must be completed as soon as possible and must be reported to employees involved in the process and to any other individuals affected by the recommendations or actions.

Every 5 years the PrHA must be updated to ensure it is consistent with the current process, configuration, and operation. The PrHA, related updates, and the documented resolution of the recommendations are required to be maintained for the life of the process.

## 4.0 SUMMARY OF RECOMMENDATIONS

**The** action items and recommendations developed by the process hazard analysis (PrHA) team during the hazard and operability (HAZOP) study are presented in Table 1. The HAZOP study worksheets from which these action items and recommendations were derived are included in Appendix B.

Action items are typically assigned to specific individuals who are named in the "Responsibility" column in the matrix. However, because this report is an example PrHA, this column is left blank.

### Table 1. HAZOP Study Action Items

| ACTION ITEM | SCENARIO | ACTION | RESPONSIBILITY |
|---|---|---|---|
| 1 | 1-4 | Check on the possibility of backflow past the rate indicator (rotameter) and adjust the procedures as needed. | |
| 2 | 1-9, 3-1 | Consider adding a procedure to verify that the vacuum can be maintained after the system is shut down to test for system leak tightness. This procedure should be used when the chlorinators are switched each month and whenever the polyethylene chlorine gas feed tubing is replaced. | |
| 3 | 1-13 | Verify that staff in adjacent buildings hsve received information on chlorine in their hazard communication (HAZCOM) program. | |
| 4 | 2-5 | Calculate possible temperatures (based on heat input versus heat loss) inside the chlorine cylinder storage facility if the heater thermostat fails "on" during peak outside temperatures. Base further action items on the results. Other key equipment affected by excessive temperatures should be considered. See the high-temperature alarm failure incident in Section 6.0. | |
| 5 | 2-8 | Check pressure potential from the chlorine cylinder and the system (regulator) response. Determine whether the fusible plug will open with high pressure. | |

## Table 1. HAZOP Study Action Items (Continued)

| ACTION ITEM | SCENARIO | ACTION | RESPONSIBILITY |
|---|---|---|---|
| 6 | 2-1o, 2-11 | Check with the vendor regarding possible entry of material other than chlorine into the chlorine cylinder or the possibility of complete substitution of another chemical that uses the same size container. | |
| 7 | 3-2 | Contact the vendor to determine the failure experience of the regulator failing "open" from wear, corrosion, dirt, or water. If the regulator has a relatively high probability of failing, controls (e.g., a remotely operated shutoff at the chlorine cylinder and failsafe action upon power loss) should be considered. | |
| 8 | 3-1o | Verify that the screens are in place on the regulator vents. | |
| 9 | 4-4 | The explanation of how the differential pressure regulator operates is missing from the vendor's documentation. This information should be obtained. The operation of the valve should be checked, and the potential for a pressure deviation should be assessed. | |
| 10 | 4-13 | Verify that monthly preventative maintenance includes checking the battery backup for the chlorine alarm. | |
| 11 | 5-24 | Ensure that the intent to incorporate the existing identification tagging into the disconnect procedures is completed. | |
| 12 | 6-16 | Consult the vendor about what the expected system response would be if the serviceman did not properly vertically align the chlorine tank (drawing liquid to the ejector). Determine the potential amount of chlorine that could be released. | |

## 5.0 PROCESS DESCRIPTION

The Hanford 300-Area Water Treatment Facility uses gaseous chlorine to disinfect the drinking water supply at the Hanford Site 300-Area in accordance with the Washington State Administrative Codes (WAC) 246-290. Two independent chlorination systems are installed at the Water Treatment Facility. These systems can be operated separately or in parallel. Because they are typically operated separately, this study addresses only one system. Figures 1 through 4 are simplified diagrams of the chlorination process. Figures 5 through 8 are photographs of the chlorine cylinder storage area and the chlorination room. The chlorination system was partially installed and not yet operating at the time of the hazard and operability (HAZOP) study.

Within the chlorine cylinder storage area of the Water Treatment Facility, liquid chlorine is stored in two l-ton cylinders (see Figures 6, 7, and 8). One cylinder is normally in service, and the other is in standby mode for use when the contents of the in-service cylinder are depleted.

Chlorine leak detection and warning are provided by two sets of alarms. The alarms sound locally at the Water Treatment Facility and remotely at a separate facility that is staffed 24 hours a day. One alarm indicates a chlorine concentration of 1.0 part per million (ppm) and is used to detect a slow buildup of chlorine. A second alarm, set at 5.0 ppm, is used to detect larger chlorine releases. The chlorine cylinder storage area is also equipped with a manually activated exhaust vent system to evacuate chlorine before personnel entry.

Chlorine cylinders are placed on trunnions and dollies to move them in and out of the storage area (see Figure 6). The dollies operate on fixed tracks with “stops” to prevent them from traveling too far. Wheel chocks prevent movement of the dollies while the chlorine cylinders are in use.

Two gaseous chlorinators are installed in a separate room adjacent to the chlorine cylinder storage area. The chlorinators meter and inject gaseous chlorine into the raw water supply as it enters the Water Treatment Facility sedimentation basins. The chlorination room is equipped with an exhaust vent fan and chlorine leak detection system. The leak detector is equipped with alarm capabilities that alarm both locally and remotely at a separate facility that is staffed 24 hours a day.

Chlorine gas is supplied from the in-service chlorine cylinder at approximately 75 psig to a vacuum regulator mounted directly to the cylinder gas supply valve. An automated switch-over valve is installed between the containers to allow both containers to be connected to the in-use chlorinator at the same time. As one container approaches depletion, a sensor detects the high-vacuum condition causing the valve to switch to the standby container. The vacuum regulator reduces the pressure from the cylinder by using a water ejector to create a vacuum within the system. The regulator is designed to fail “closed” any time a loss of vacuum is experienced within any component of the system. The regulator is also designed to relieve the pressure from the system.

Gaseous chlorine is drawn through a flow rate **indicator/controller,** an automatic control valve, and a differential pressure regulator, to a water ejector. The chlorine rate indicator is set manually to maintain a **feed** rate of 20 to 60 pounds per day. Feed rate depends on ambient weather conditions and the quantity of water processed. Chlorine gas is mixed with water from the clear-well as the gas passes into the water **stream** at the water ejector. The chlorinated water is then discharged into the raw water supply at the influent chamber, where initial treatment of the water supply begins. The water undergoes sedimentation and filtering (rapid sand filters) before entering the 70,000-gallon clear-well reservoir.

The water system is monitored during each shift for residual chlorine. Monitoring occurs at the clear-well and at various **facilities** throughout the Hanford **300-Area** to assure that the proper amount of chlorine is present to effectively disinfect the water supply. Depending on the results of the monitoring, the chlorine **feed** rate is manually adjusted to maintain sufficient chlorine for disinfection.

Chlorine cylinders are delivered to the chlorine cylinder storage building on flat bed trucks as needed. The cylinders are loaded and unloaded from the truck using a mobile crane. Hoisting and rigging crews are trained to perform the loading and unloading activities.

In **case** of system outages, a water line from the City of **Richland** can temporarily supply water to the Hanford 300-Area.

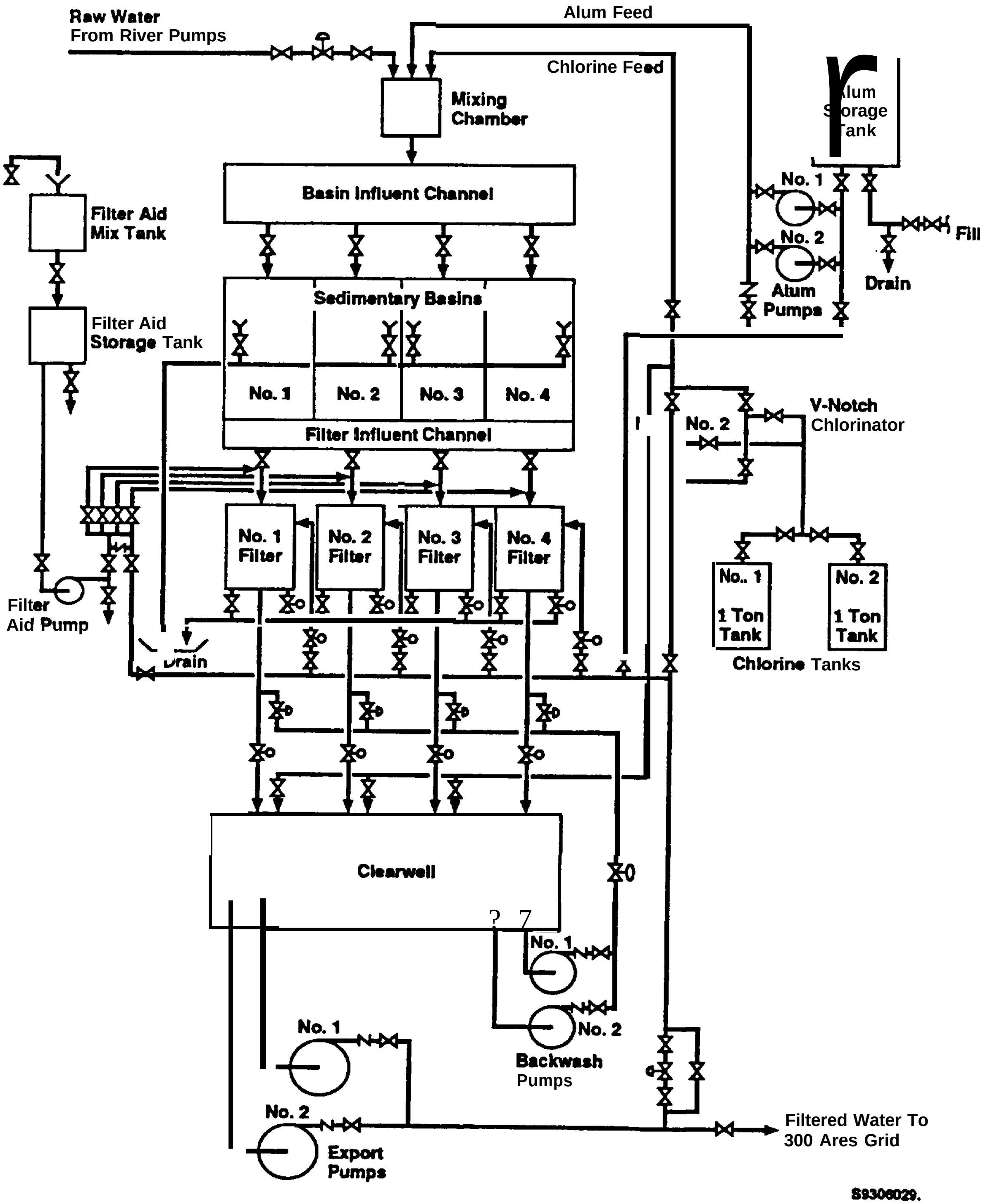
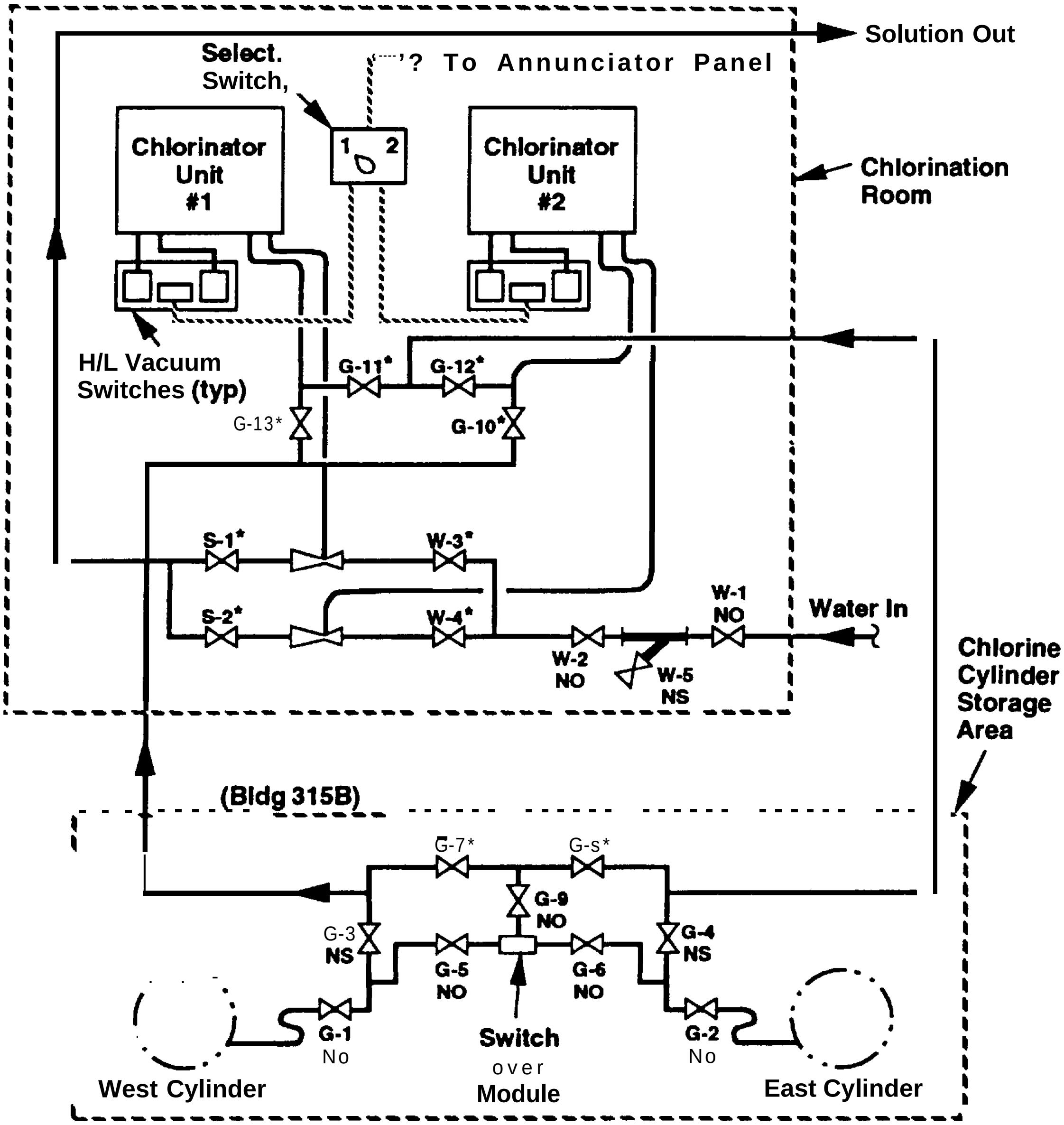



**Figure** 1. Process Flow Diagram of the Hanford 300-Area Water Treatment Facility




**Notes:**

* - Position depends on which chlorinator or cylinder and/or chloine supply iine is in-service

NO - Normally open

NS - Normally shut

39306007.1A

Figure 2. Chlorination Process Flow Diagram, Water Treatment Facility

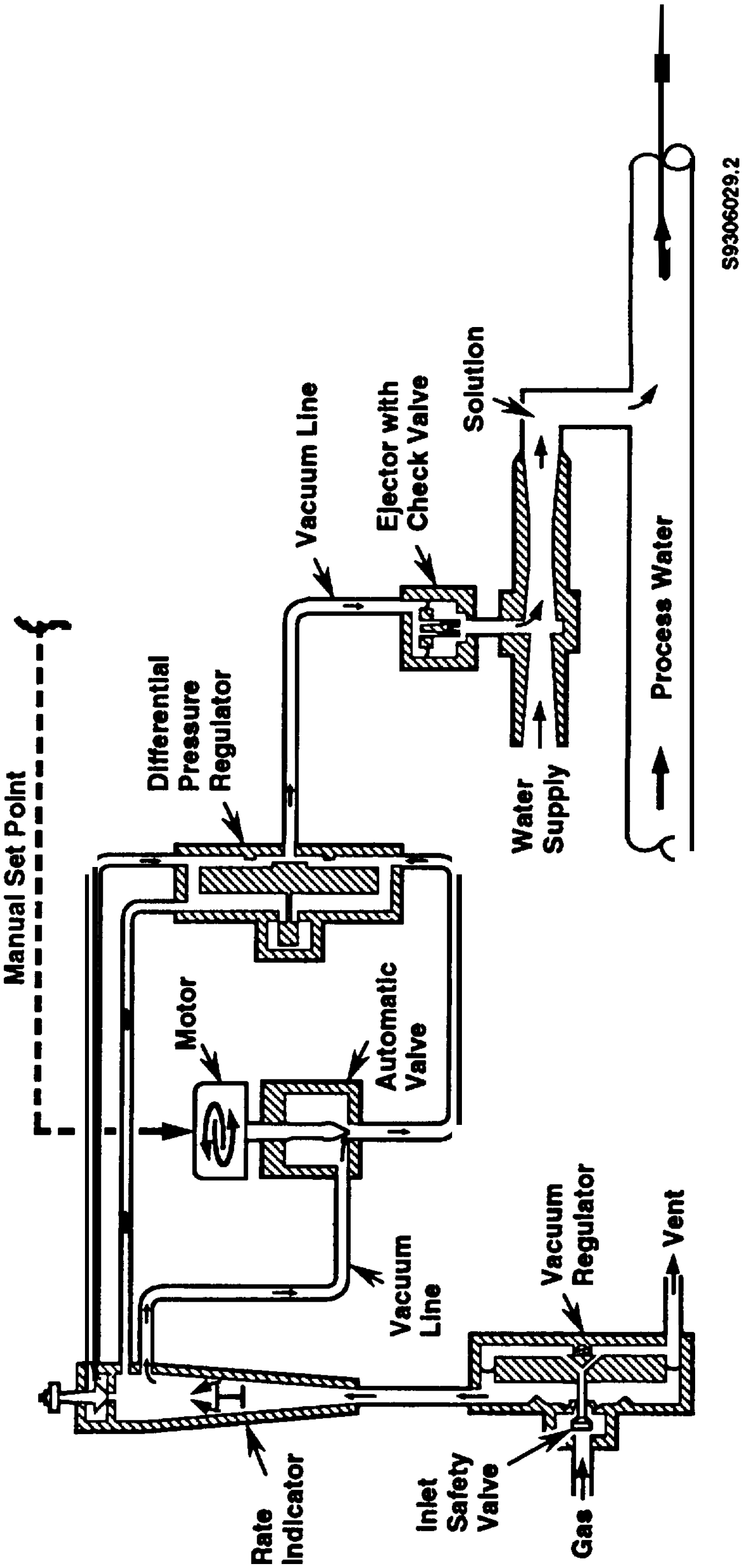



Figure 3. Automatic Gas Feed System, Chlorination Process

# PARTS LIST

**VACUUM REGULATOR**
**CHLORINE**
**200 PPD (4kg/h) MAXIMUM**

**CAPITAL CONTROLS**
**COMPANY, INC**
PO Box 211

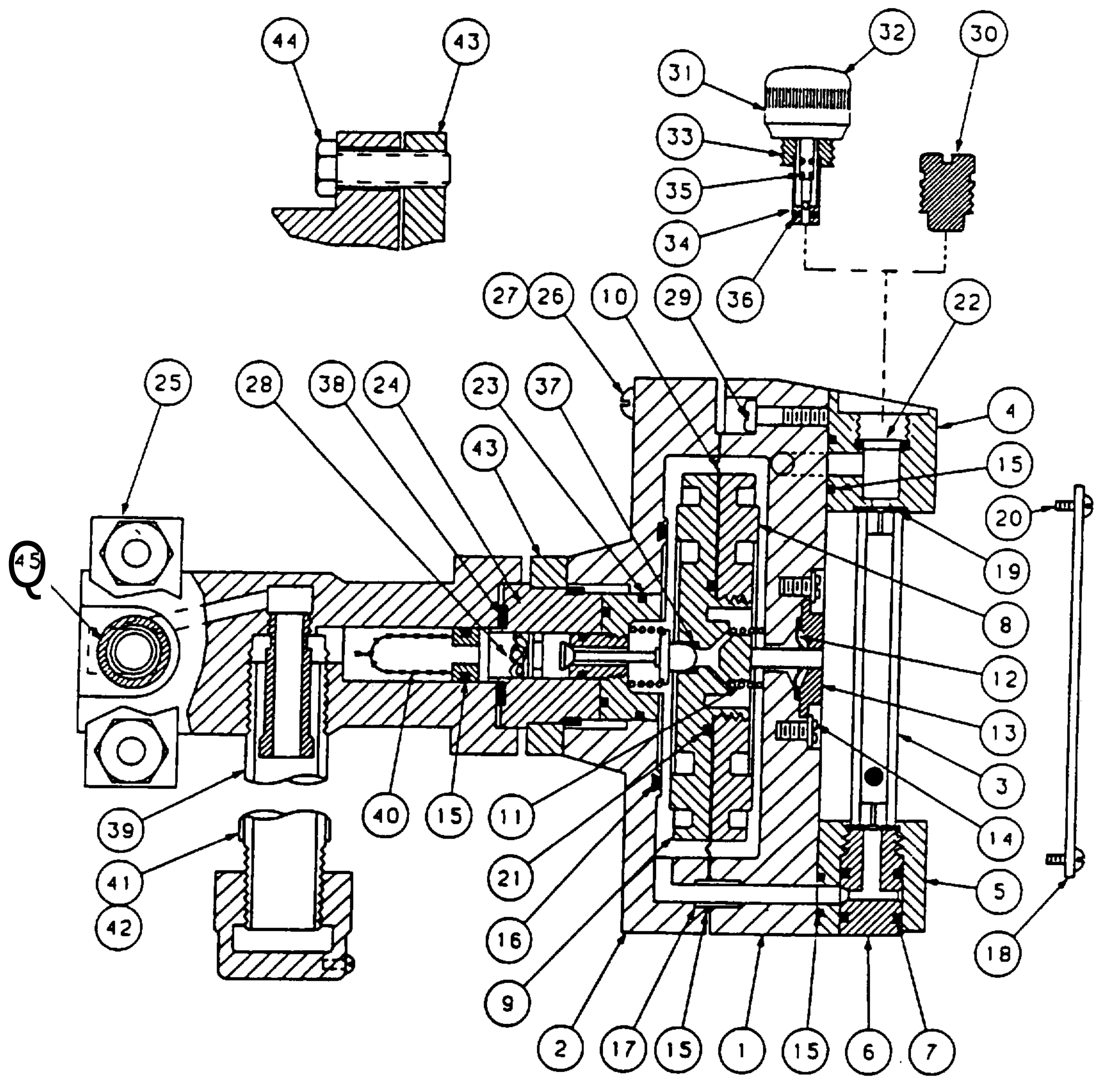





**Figure 4**. Vacuum Regulator, Automatic Gas Feed System

| ITEM NO. | QTY. | DESCRIPTION | PART NO. | ITEM NO. | QTY. | DESCRIPTION | PART NO. |
|---|---|---|---|---|---|---|---|
| 1 | 1 | FRONT BODY | SEE CHART IV | 26 | 2 | SCREW, 1/4-20 X 2-3/4 LG | N-125 |
| 2 | 1 | BACK BODY | U-160 | 27 | 6 | SCREW, 1/4-20 X 1-3/4 LG | N-124 |
| • 3 | 1 | FLOWMETER ASSEMBLY | SEE CHART I | + 28 | 1 | REPLACEMENT FILTER (SEE NOTE 6) | I3M-1023 |
| 4 | 1 | FLOWMETER TOP FITTING | M-117 | 29 | 4 | SCREW, 10-24 X 1 LG | N-126 |
| 6 | 1 | FLOWMETER BOTTOM FITTING | M-1 16 | 30 | 1 | BONNET PLUG | M-176 |
| + 6 | 1 | METER INLET PLUG | U-140 | 31 | 1 | RATE VALVE ASSEMBLY | SEE NOTE 3 |
| + 7 | 2 | O-RING | OV-11-112 | 32 | 1 | VALVE STEM ASSEMBLY | SEE CHART I |
| + 8 | 1 | DIAPHRAGM FRONT PLATE | U-269 | 33 | 1 | VALVE BONNET | V- 124 |
| + 9 | 1 | DIAPHRAGM BACK PLATE | A-363 | 34 | 1 | VALVE SLEEVE | SEE CHART I |
| + 10 | 1 SET | DIAPHRAGM (2 PER SET) | 0-106 | + 36 | 2 | O-RING | OV-11-006 |
| 11 | 1 | RELIEF SPRING | s-loo | + 36 | 1 | O-RING | OV-11-010 |
| + 12 | 1 | SEALING DIAPHRAGM | D- 102 | + 37 | 1 | O-RING | Ov-11 -009 |
| 13 | 1 | SEAL COVER | U-137-1 | + 38 | 1 | LEAD GASKET (SEE NOTE 6) | G-ill |
| 14 | 2 | SCREW, 10-24 X 3/16 LG | N-128 | 3s | 1 | INLET ASSEMBLY | SEE CHART III |
| + 16 | 4 | D-RING | OV-11-012 | + 40 | 1 | INLET FILTER ASSEMBLY | BM-1276 |
| + 16 | 1 | O-RING | OV-1 1-332 | " 41 | 1 | HEATER | SEE CHART II |
| + 17 | 1 | FLOW TUBE | U-162 | + 42 | 2 | MOUNTING CUP | T-458 |
| 18 | 1 | FRONT PLATE | R-2204 | 43 | 1 | BODY PLATE | T-1 163-1 |
| " 19 | 2 | METER GASKET | SEE CHART I | 44 | 2 | BOLT. HEX 3/8-16 X 1 LG | N-139 |
| 20 | 2 | SCREW, 6-32 X 1/4 LG | N-302 | 46 | 1 | LEAD GASKET (SEE NOTE 5) | SEE CHART III |
| + 21 | 1 | O-RING | OV-1 1428 | NS | 1 | 3/8 TUBING CONNECTOR (VENT) | F-loo |
| + 22 | 1 | O-RING | OV-11-110 | + N/S | 1 | 1/2 TUBING CONNECTOR (VACUUM) | F-106 |
| + 23 | 1 | O-RING (SEE NOTE 6) | OV-11-212 | | | | |
| + 24 | 1 | INLET CAPSULE ASSEMBLY | BM-4869 | | | | |
| 26 | 1 | YOKE ASSEMBLY (SEE NOTE 4) | SEE CHART III | | | | |

N/s - NOT SHOWN

CHART I

| ITEM NO. | CAPACITY IN PPD (KG/H) | | | |
|---|---|---|---|---|
| | 25 (0.5) | 50 (1.0) | 100 (2.0) | 200 (4.0) |
| 3 | A-108-6 | A-108-6 | A-108-8 | A-108-9 |
| 19 | G-100-6 | G-100-7 | G-100-7 | G-100-4 |
| 31 | BM-11 8-3 | BM-1 18-3 | BM-11 B-3 | BM-11S-4 |
| 32 | A-659-3 | A-659-3 | A-659-3 | A-659-4 |
| 34 | V-1 26-3 | V- 126-3 | v-126-3 | V-126-4 |

CHART II

| ITEM NO. | VOLTAGE | |
|---|---|---|
| | 120 VAC 25 WATT | 240 VAC 25 WATT |
| 41 | R-ill | R-260 |

CHART III

| ITEM NO. | CONNECTIONS | | |
|---|---|---|---|
| | U.S. LEFT HAND | U.S. RIGHT HAND | JAPAN |
| 25 | A-128 | A-128 | A-825 |
| 39 | A-738-L | A-738-R | BM-1 160 |
| 46 | G-ill | 0-111 | G-120 |

CHART IV

| ITEM NO. | WITH LOSS OF GAS SWITCH | WITHOUT LOSS OF GAS SWITCH |
|---|---|---|
| 1 | SEE P/L B3.7 133 | A-107 |

NOTES:

1. (+) AND (•) INDICATES RECOMMEND ED AS MINIMUM SPARE PARTS. QUANTITY RECOMMENDATIONS ARE FOR AVERAGE USE AND CONDITIONS. ADDITIONAL PARTS AND QUANTITIES SHOULD BE CONSIDERED WHERE THE EQUIPMENT IS USED TO ITS FULLEST CAPABILITY OR WERE LOCATED IN AN AREA REMOTE FROM CONVENIENT SERVICE.
   - (A) TO ORDER RECOMMENDED SPARE PARTS INDICATED BY (+) SPECIFY BM-3259.
   - (B) TO ORDER RECOMMENDED SPARE PARTS INDICATED BY 1" ) SPECIFY INDIVIDUAL PARTS.
2. WHEN ORDERING PARTS, SPECIFY GAS FEEDER CAPACITY, MODEL NUMBER, ANO SERIAL NUMBER.
3. ITEM NO. 31 INCLUDES ITEM NOS. 22, 32, 33, 34, 36, AND 36. TO ORDER COMPLETE RATE VALVE ASSEMBLY BEE CHART L
4. ITEM 26 YOKE ASSEMBLY IS INCLUDED IN ITEM 39 INLET ASSEMBLY.
6. TO ORDER TWELVE (12) GASKETS SPECIFY THE FOLLOWING:
   FOR G-1 11 SPECIFY BM-918
   FOR G-120 SPECIFY BM-919.
6. ITEM 23 O-RING AND ITEM 2B FILTER INCLUDED IN ITEM 24 INLET ASSEMBLY.

Figure 4. Vacuum Regulator, Automatic Gas Feed System (continued)

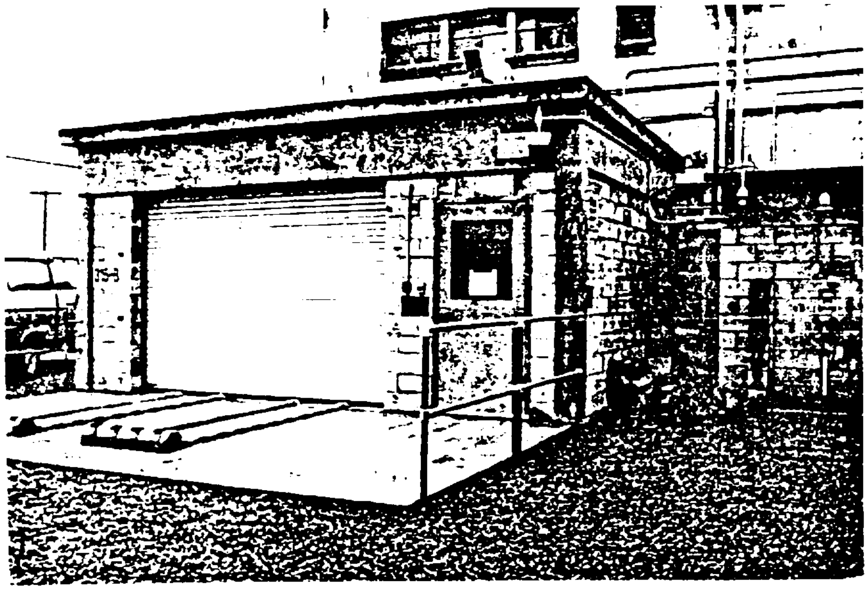


Figure 5. Building Housing Chlorine Cylinders and Chlorination Process Equipment

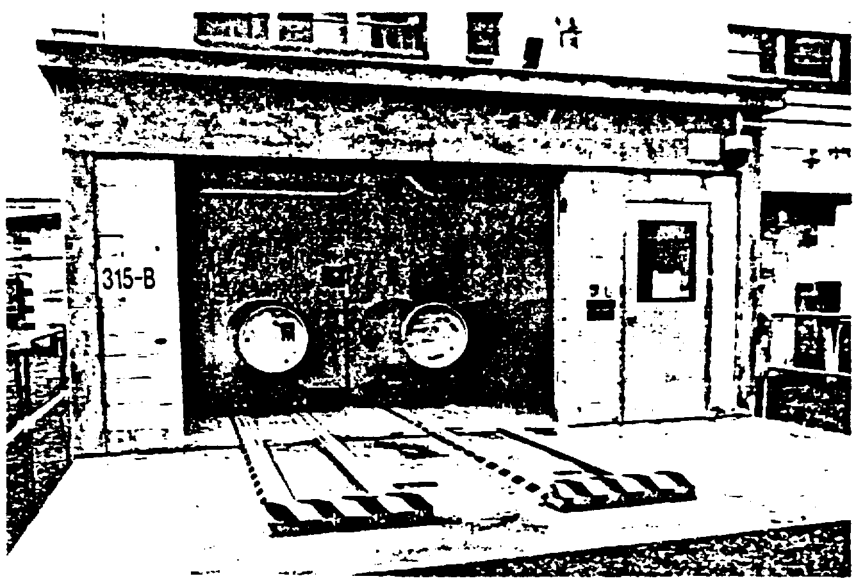



Figure 6. Chlorine Cylinder Storage and Change-out Area, Overhead Door Open

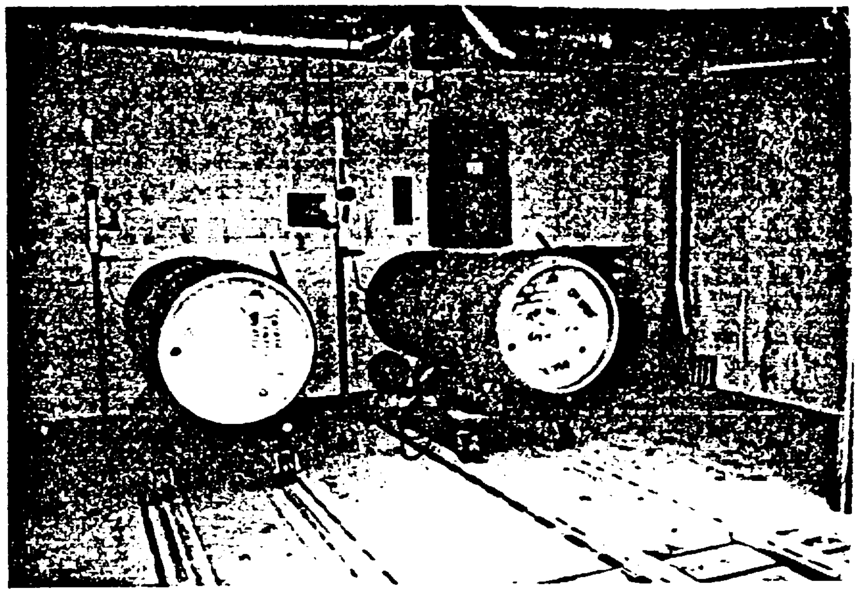


**Figure** 7. Chlorine Cylinders in the Chlorine Cylinder Storage Area, Front View

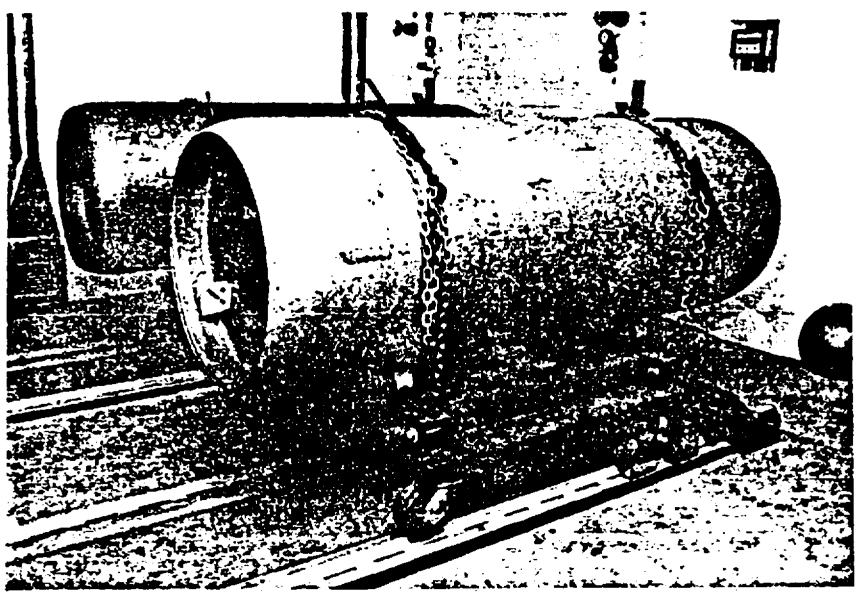


Figure 8. Chlorine Cylinders in the Chlorine Cylinder Storage Area, Side View

## 6.0 REVIEW OF PREVIOUS INCIDENTS

The following incidents involved the former chlorination system for the Hanford 300-Area Water Treatment Facility. Information about these incidents was obtained from the U.S. Department of Energy (DOE) Occurrence Reporting and Processing System (ORPS). Where relevant, these incidents were considered during the hazard and operability (HAZOP) study for the new system.

- 10/9/92 **Leak Detector Failure — The** leak detector was outside of specified tolerances, as required in the maintenance procedure. Plant operations personnel were notified. Replacement parts were not available, and the maintenance craftsman removed the device from service until parts could be obtained the next day. During the swing and the following day shift, personnel did not know the detector had been removed from service. A "conduct of operations" review of the day's activities was held with all on-coming and off-going staff. This leak detector had experienced recurring failures and was replaced. (See Scenario 5-2 in the HAZOP study worksheets, Appendix B.)

- **11/19/92 Chlorine Leak — The** chlorine detector in the chlorination room alarmed in the afternoon, indicating that one of the chlorinators was leaking. Facility operations personnel were evacuated, and the Hanford Fire Department Emergency Response Team was notified. The system was shut down, the in-service chlorinator was isolated, and the standby chlorinator was put into service. No one was injured, and only a minimal amount of chlorine was released. The chlorine was generally confined to the chlorination room. It was determined that the #1 chlorinator injector system had developed a leak. The system tiled because of imperfections within gasket material. The failed material was replaced. (See Scenarios 1-4, 1-10, and 4-9 in the HAZOP study worksheets, Appendix B.)

- **11/21/92 Chlorine Leak —** A chlorine alarm was received, the Hanford Fire Department was notified, and the Hanford Hazardous Materials (HAZMAT) Team was dispatched. The Hanford 300-Area Water Treatment Facility was shut down. **A** tie-in line was put into service to supply water to the Hanford 300-Area from the City of Richland after Richland was notified. Failed internal parts of the #2 chlorinator and a system isolation valve packing gland were leaking. A weak spring in a chlorinator pressure-regulating valve caused a rubber diaphragm to fail. There were no injuries, and the minimal amount of chlorine released was generally confined to the chlorination room. The spring and diaphragm were replaced. The isolation valve was repacked. (See Scenarios 1-10 and 1-4 in the HAZOP study worksheets, Appendix B.)

- **1/4/93 Chlorine Leak Detector** Alarm — While performing routine equipment changes, the onduty operator noticed a chlorine odor in the chlorination room. After the operator exited, the chlorine leak detector in the building alarmed. The plant operator evacuated the Water Treatment Facility, and the Hanford HAZMAT

Team responded and isolated the system. The Water Treatment Facility was shut down, and the City of Richland water supply was placed in service. There were no injuries from the occurrence.

During maintenance activity, the operator had isolated and drained the in-service chlorinator according to procedures in effect at the time. These procedures did not allow sufficient time for evacuating the chlorine ejector prior to draining the chlorinator. The system was checked for leaks, but no leaks were found. The procedure was revised to allow sufficient time to evacuate the system. With different procedures now in place, this incident has consequences similar to Scenario 1-11 in the HAZOP study worksheets (see Appendix B).

- 1/16/93 Chlorine Leak **Detection Alarm —** A chlorine high-level alarm occurred. The Hanford Fire Department was notified, and several surrounding buildings were evacuated. Testing by the Hanford HAZMAT Team found no detectable chlorine in the air. Fewer than two hours later, the "all clear" was given. It was determined that the detector provided a false alarm. Tests performed by an instrument technician, however, showed that the detector was operating within the manufacturer's recommended tolerances. No leaks were identified when the system was restored to operation.

  Prior to the occurrence, re-liquefaction of the gaseous chlorine within the chlorination room piping had been occurring. An additional heat source had been provided to rectify the problem. The heater had been placed next to the leak detector. The detector's electronics were affected by the increased room temperature. A voltage spike was created within the instrument and resulted in the false alarm. (See Scenarios 5-2 and 2-5 in the HAZOP study worksheets, Appendix B, and recommendation #4 in Section 4.0.)

# 7.0 IDENTIFIED HAZARDS

Chlorine has been used for many years to treat water on the Hanford Site. Westinghouse Hanford Company uses the Chlorine ***Manual*** (The Chlorine Institute, 1986, 5th edition), ***Operating Procedure: Chlorine Cylinder Handling and Storage*** (Westinghouse Hanford Company, no date), and the ***Material Safety Data Sheet*** **(MSDS)** (Occupational Health Services, Inc., 1993; **see** Appendix D) as references for chlorine handling.

## 7.1 Properties **of Chlorine**

Chlorine is a dense, nonflammable, greenish-yellow gas with a **bleach-like** choking odor. It is ***2.5*** times heavier than air. Liquid chlorine is a clear amber color and is 1.5 times heavier than water. Chlorine is generally shipped as a compressed, **liquified** gas with a vapor pressure of ***85.5*** psig at **70°F.** In both gaseous and liquid states, chlorine is nonflammable and nonexplosive. However, like oxygen, it is capable of supporting the combustion of substances such as hydrogen, ammonia, fuel gases, ether, turpentine, and most hydrocarbons. Finely divided metals and organic matter may react violently with chlorine. Steel and iron ignite and bum in an atmosphere of chlorine at about **484°F.** Chlorine reacts with water to form corrosive solutions of hydrochloric and **hypochlorous** acid.

## 7.2 Physiological **Effects**

Chlorine is corrosive, highly toxic, and severely irritating to all living tissue. Exposure may cause skin bums, permanent eye damage, and damage to the respiratory system. Inhalation exposure to higher **concentrations** of chlorine may be fatal. Airborne concentrations of chlorine above 3 to 5 parts per million **(ppm)** by volume are readily detectable by a normal person. In higher concentrations, the irritating effect of chlorine makes it unlikely that any person would willingly remain in a chlorine-contaminated atmosphere.

Persons exposed to airborne concentrations of chlorine greater than 15 ppm generally experience difficulty in breathing. Excessive or prolonged exposure causes pulmonary edema and death. The physiological effects of various concentrations of chlorine gas **are** shown in Table 2 along with the limits for chlorine exposure in the workplace. Appendix C includes graphs that estimate the areas affected by various chlorine release scenarios. Exposure to chlorine produces no known cumulative effects.

Table 2. Physiological Responses and Exposure Limits for Chlorine Gas Concentrations

| Effects/Emits | Parts per Million (ppm) by Volume |
|---|---|
| Threshold limit value[a] | 0.5 |
| Least detectable odor[b] | 3.5 |
| Least amount required to cause irritation of throat[b] | 15 |
| Immediately Dangerous to Life or Health (IDLH) concentration[c] | 30 |
| Dangerous for short exposures[b] | 50 |
| Fatal for brief exposures[b] | 1,000 |

(a) American Conference of Governmental Industrial Hygienists, 1992.
(b) Sax, *et al.*, 1979.
(c) National Institute for Occupational safety and Health, 1990.

# 8.0 ANALYSIS METHOD

The analysis method used in this example process hazard analysis (PrHA) was the hazard and operability (HAZOP) study. The HAZOP study was developed specifically for process industries to identify both safety hazards and operability problems that could compromise a plant's ability to achieve design productivity.

The basic concept behind HAZOP studies is that processes work well when operating under design conditions, and that deviations from process design conditions cause hazards and lead to operability problems. In a HAZOP study, guide words are used to assist an analysis team in considering the causes and consequences of deviations from design conditions. The guide words are applied at specific points or "nodes" in a process and are combined with process parameters to identify potential deviations.

The HAZOP study method entails analyzing hazardous events (accidents) to see how they may occur and what undesired consequences are possible. Each sequence of failures and conditions leading to an accident event is a unique scenario. Every accident scenario includes an *initiating event* or cause (e.g., mechanical or human failure), a *process deviation(s), an accidental event* or *consequence,* and an *impact* (injuries and/or damage). *Protection* may be employed to keep the accident from occurring. *Mitigation* may reduce the severity of the impact (see Figure 9).

The HAZOP methodology

- Postulates deviations from design intent
- Examines the causes of the deviations
- Determines the consequences and range of potential impacts if deviations are allowed to continue uncorrected
- Assesses the protection included in the system design to reduce the likelihood of the cause and/or to prevent or minimize the consequences or impacts.

A HAZOP study requires considerable knowledge of the process being studied, its instrumentation, and its operation. This information is usually provided by team members who are experts in these areas. Where weaknesses or safety improvements in the design or operating procedures are identified, the HAZOP study team develops a list of action items to be further addressed.

Based on the level of complexity and the general nature of the chlorination process at the Hanford 300-Area, the HAZOP study is an appropriate PrHA method to analyze the hazards of the operation.

For a more detailed description of the HAZOP study method and other PrHA methods, see the *DOE Guideline: Guide For Chemical Process Hazard Analysis (Draft*, DOE/EH, March 1993) and the *Guideline for Hazard Evaluation Procedures* (Center for Chemical Process Safety, 1992, 2nd edition).

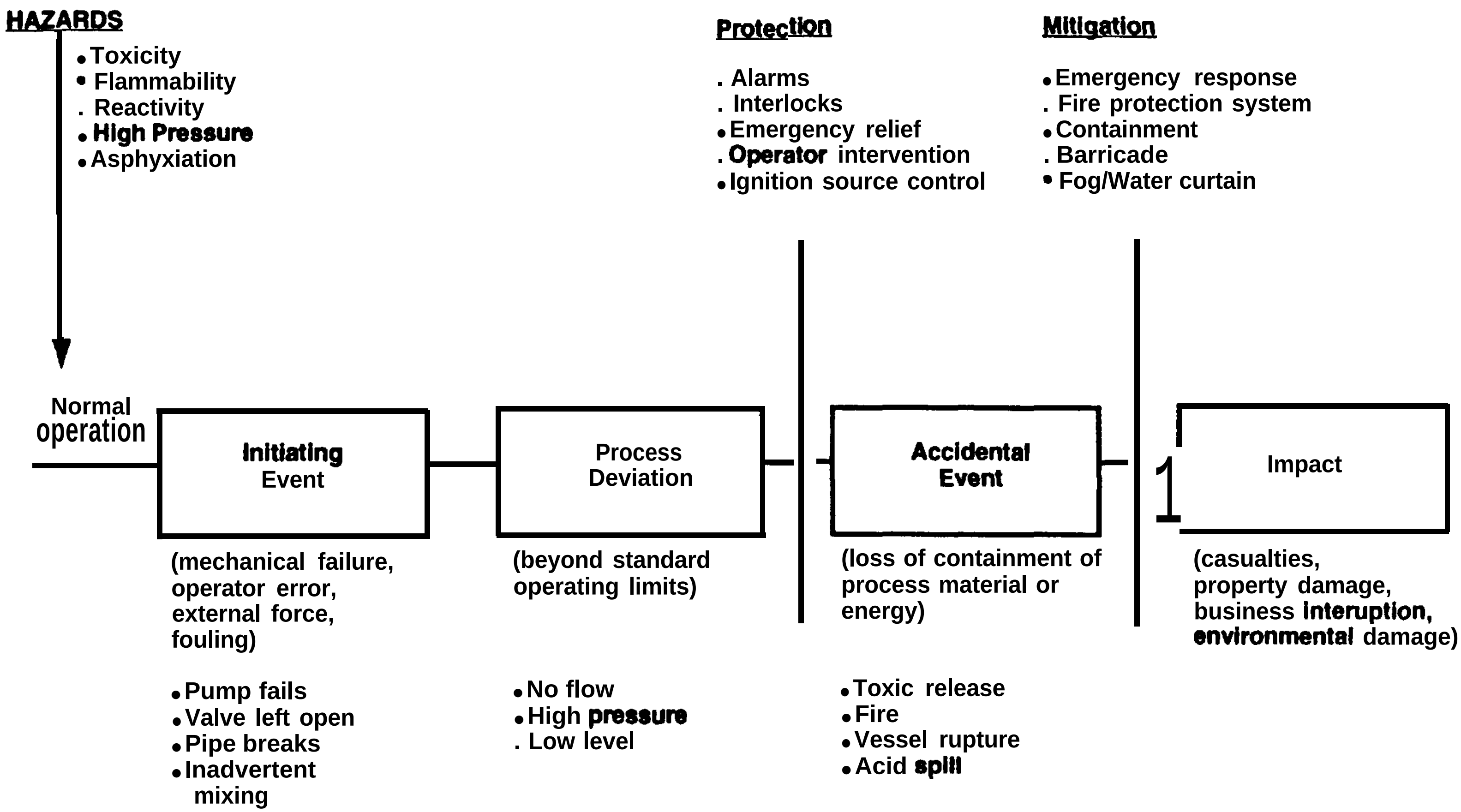



Figure 9. Anatomy of an Incident

## 9.0 ANALYSIS TEAM

The hazard and operability (HAZOP) study team consisted of the team leader, Mr. Fred Leverenz, from Battelle's Process Safety and Risk Management Group; Westinghouse Hanford Comparty (WHC) personnel; representatives from the U.S. Department of Energy (DOE) Headquarters and Richland Operations Office; and personnel from the Pacific Northwest Laboratory (PNL) Training Group and Risk and Safety Analysis Group.

Table 3 lists the personnel who participated in the 4-day HAZOP study. Appendix E contains the resumes of the HAZOP study team.

**Table 3. HAZOP Study Team Members**

| PARTICIPANT | ORGANIZATION | ROLE |
|---|---|---|
| Fred Leverenz | Battelle-Columbus | PrHA Expert and Team Leader |
| Karl Agee* | Westinghouse Hanford Company | Team Member |
| Joe Angyus | Pacific Northwest Laboratory | Team Member |
| Samuel Camp, Jr. | Westinghouse Hanford Company | Process Operator and Team Member |
| Rudy Hansen | Pacific Northwest Laboratory | scribe |
| Sanji Kanth* | DOE Headquarters | Team Member |
| Ken Murphy* | DOE Headquarters | Team Member |
| Dickie Ortiz | DOE Richland Operations Office | Team Member |
| Pete Pelto* | Pacific Northwest Laboratory | Team Member |
| John Piatt* | Pacific Northwest Laboratory | Team Member |
| Jay Rude | Westinghouse Hanford Company | Process Engineer and Team Member |

* Partial attendance

# 10.0 FACILITY SITING ANALYSIS

As part of the process hazard analysis (PrHA), a walkdown of the Hanford 300-Area Water Treatment Facility was performed on May 22, 1993. The following is a description of the general layout of the facility.

The Hanford 300-Area Water Treatment Facility is located within the fences of the Hanford 300-Area and away from offsite populations. Most near-by human activities are related to facility operations and/or chlorine delivery and associated crane manipulations.

The Columbia River is directly east of the Water Treatment Facility. The closest residences are isolated houses on the opposite side of the river, more than three-quarters of " a mile away. A pump house is located east of the facility near the river. The east access road, which supports only low levels of traffic, is more than 120 feet away, at a lower elevation.

The chlorination room (80 square feet) and the chlorine cylinder storage area (300 square feet) are on the north side of the 315 Building. The building closest to the chlorination process is the 338 Maintenance Shop. It is more than 60 feet to the west of the chlorination room. This building is being transferred from the Westinghouse Hanford Company (WHC) to Kaiser Engineers, Inc., to be used as a fabrication shop. About 20 to 40 employees will eventually occupy the building.

Other buildings in the vicinity of the chlorination process are the 337 Office Building (325 employees), which is more than 200 feet to the south, and the 3768 Modular Office Building (15 employees), which is more than 150 feet to the north. To the north of the 3768 Building are the 3769 Modular Office Building (15 employees), the M103 trailer (7 employees), the M105 trailer (9 employees), and the 3770 Modular Office Building (15 employees). All buildings have multiple exits and emergency plans. The emergency plan evacuation route for the 337 Office Building is toward the south, away from the chlorination process. The emergency plan addresses leaks and spills, as well as unusual, irritating, or strong odors.

The regulator for the chlorine cylinders vents near the roof level of the chlorine cylinder storage area. ShutOffs (G 1 and G2) for the chlorine feed are inside the storage area. See Appendix C for potential impacts of chlorine releases.

## 11.0 HUMAN FACTORS

The Occupational Safety and Health Administrative (OSHA) rule on process safety management (the PSM **Rule)** requires the inclusion of human factors in process hazard analyses **(PrHAs).** Human factors may positively or negatively influence the likelihood of an operator making an error when interacting with a process. For example, if an operator is required to change the position of a valve, but the location of the valve is not specified and/or the valve is not labeled, the operator may have difficulty responding correctly. More positively, if an operator has enough time to complete an action such that he/she can verify the action, then it is more likely that the operator will act correctly.

Human **factors** are included in this hazard and operability **(HAZOP)** study by adding notations in the ***CAUSE*** or ***PROTECTION*** column of the HAZOP study worksheets (see Appendix B) immediately after a human error is indicated. The notation used is "—I-IF" for human factors that may negatively influence an operator's performance and **"+HF"** for human factors that may help an operator to act correctly.

In some places in the HAZOP study worksheets, human interactions/errors are indicated, but no notation is present. If no human **factors** notifications are present, the HAZOP study team judged that the human factors components of that scenario were "normal, " expected good practice. For example, the HAZOP study team assumed that **all** equipment **was** labeled.

Table 4 provides a generic checklist for human factors. This list is recommended for use by PrHA teams to help recognize the human factors that influence each accident scenario.

## Table 4. Human Factors Checklist

| FACTORS | EXPECTED (+) | NEGATIVE (–) |
|---|---|---|
| DISPLAYS/CONTROLS | Essy to read/understand | Hard to read/understand/interpret |
| | Controls accessible | Controls inaccessible |
| | Display identifies related device | Display does not show device |
| | Alarms discriminable, relevant | Alarms confusing, irrelevant |
| | Display mimics action/position | Display is not representational |
| | Immediate feedback | No immediate feedback |
| EQUIPMENT | Clearly labeled | Not labeled or mislabeled |
| | Accessible | Not easily accessed |
| | Easily operated | Difficult to operate/change position |
| | Components easy to distinguish | Several components look similar |
| PROCEDURES | Realistic; reflect the way things are done | Unrealistic; not the way things are done |
| | Location of devices/action provided | No location of devices/action provided |
| | Allows unambiguous determination of event in progress | Results in inappropriate diagnosis |
| | Clear, consistent format | Confused, difficult to read |
| | Complete and accurate | Missing step in procedure or wrong sequence |
| COMPETENCE | Operators generally well trained in related procedures | Operators not well trained in related procedures |
| | Operators have considerable experience | Operators are novices |
| | Peer review used in certification | No peer review in certification |
| | Operators given periodic feedback on performance | No feedback |
| | Design changes are appropriately reviewed | Design changes performed without adequate review |

**Table 4. Human Factors Checklist (Continued)**

| FACTORS | EXPECTED (+) | NEGATIVE (–) |
|---|---|---|
| STRESS | Adequate time available to complete action | Too little time available to complete action |
| | Shift assignments are permanent, or shift changes do not create time confusion | Shift changes often occur in the middle of the week; double shifts often occur |
| | Staffing is at an appropriate level | Staff are needed, or some shifts are intentionally short-staffed |
| | Safety is emphasized | Operators are concerned about 10ss of production if plant inadvertently shut down for safety issue |
| | Accountabilities are well defined | Accountabilities are poorly defined |
| | operator performs acceptable number of tasks | Operator must conduct diverse operations within same time period |
| ENVIRONMENT/ WORKPLACE | Sufficient lighting | Inadequate lighting |
| | Minimal noise level | High noise level |
| | Moderate weather | Extreme weather conditions |
| | Comfortable temperature/humidity | Extreme temperature/humidity |
| | Low vibration environment | High vibration environment |
| | Good job aids | No memory support |

## 12.0 SUMMARY

During the process hazard analysis (PrHA) of the chlorination process at the Hanford 300-Acre Water Treatment Facility, areas of uncertainty were identified. Twelve action items and recommendations were made by the PrHA team to clarify these uncertainties and to verify process conditions (see Section 4.0). These recommendations are being reviewed to determine whether further action is needed to improve the chlorination system. In addition, procedures were developed during the PrHA exercise to control and avoid potential hazards.

To comply with the Occupational Safety and Health Administration (OSHA) rule on process safety management (the PSM Rule), all of the PrHA findings and recommendations must be resolved and documented. All actions taken as a result of the PrHA findings must be reported to employees involved in the process and to any other affected individuals. In addition, the PrHA must be reviewed every 5 years to ensure that it is consistent with the current configuration and operation of the chlorination process. The PrHA, related updates, and the documented resolution of the recommendations must be maintained for the life of the process.

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# APPENDIX A

# PROCEDURES FOR CHANGE-OUT OF CHLORINE CYLINDERS

# APPENDIX A: PROCEDURES FOR CHANGE-OUT OF CHLORINE CYLINDERS

## PART I: Removal of Cylinder

*Assumptions:*

- ***Replace** west **cylinder** with chlorinator #1 in service (valves* G3, G8, G4, S2, W4, ***G1O, Gil, and*** G12 ***are closed to supply chlorinator #l).***
- ***Serviceman** and **operator** wear **coveralls.***

1. Notify the 384 Powerhouse and the Hanford Fire Department that the chlorine cylinder change-out is in progress.
2. Start the 315B Building vent **fan** and operate it for three (3) minutes before entering. Maintain the vent fan continuously. (Alarms operate at 1 and 5 **ppm.)**
3. Enter through the walk-through door.
4. Identify the empty cylinder by its weight, and verify the indication of no flow on the cylinder regulator.
5. Close the angle (root) valve on the chlorine cylinder.
6. Isolate the automatic **switchover** valve. (Close valves G5, G6, and G9.)
7. Verify that valves G8 and G4 are closed.
8. **Verify** that valve G 1 is open, and open valve G3. Wait two (2) minutes and verify that there is no flow at the chlorinator in service. Verify that the high-vacuum alarm is actuated.
9. Close valves G 1 and G3. Open valves G6 and G9, and verify that the high-vacuum alarm clears.
10. Chlorine serviceman dons the **facemask,** and operator dons self-contained breathing apparatus **(SCBA).** Then they verify the operation of the personal protective equipment.
11. Slowly disconnect the regulator, check it for **leaks,** and set it on the floor.

12. Install the cap on the cylinder angle valve, and install the protective hood.

13. Position the crane and cylinder truck for loading; open the roll-up door; remove the chocks; and push the cylinder out to the stops.

14. Release the chain binders, and turn the cylinder over to the hoist and rigging crew.

15. Install the spreader bar, lift the cylinder, and place it on the flatbed truck.

16. Secure the cylinder and transport it.

17. Close the roll-up door, and exit through the walk-through door.

## PART II: Installation of Replacement Cylinder

1. Turn on or verify that the storage room exhaust fan is on.
2. Position the crane for unloading.
3. Position the chlorine transport truck for unloading.
4. Verify that the chlorine cylinder trolley is in position to receive the cylinder.
5. Release the cylinder binder(s) on the transport vehicle.
6. Install the lifting bar, and lift the cylinder.
7. Place the cylinder on the trolley.
8. Remove the lifting bar, removing it from the immediate area.
9. Secure the cylinder to the trolley with chain binders (2).
10. Enter through the walk-through door, and open the roll-up door.
11. Push the trolley and the chlorine cylinder into the building and against the rail stop. Install the wheel chocks.
12. Request the chlorine serviceman to remove the protective hood from the chlorine cylinder.
13. Observe the position of the cylinder angle valves. If the valves are not in vertical alignment, loosen the chain binders and rotate the cylinder to obtain vertical alignment of the valves, and then tighten the chain binders.
14. Chlorine serviceman dons the facemask respirator, and operator dons self-contained breathing apparatus (SCBA) equipment. Then they verify the operation of the personal protective equipment.
15. Verify that the chlorine cylinder gas angle valve is closed.
16. Check for leaks while slowly removing the protective cap from the cylinder gas angle valve.
17. Clean the sealing surface of the gas angle valve and the vacuum regulator. Visually inspect the regulator valve body for damage.

18. Install a new lead seal. Attach the regulator to the cylinder gas valve, and secure it in place by tightening the yoke assembly.

19. Check for leaks. Slowly open the chlorine cylinder gas supply valve.

20. Adjust the cylinder weight scale to indicate 2,000 pounds of product available in the cylinder.

21. Open system supply valves G1 and G5.

22. Record in the log book the chlorine cylinder identification number and the scale weight.

23. Report any deficiencies to the supervisor for initiation of necessary corrective action.

24. Notify the Hanford Fire Department and the 384 Powerhouse that the chlorine cylinder change-out activities are complete.

25. Close the roll-up door, and exit through the walk-through door.

# APPENDIX B

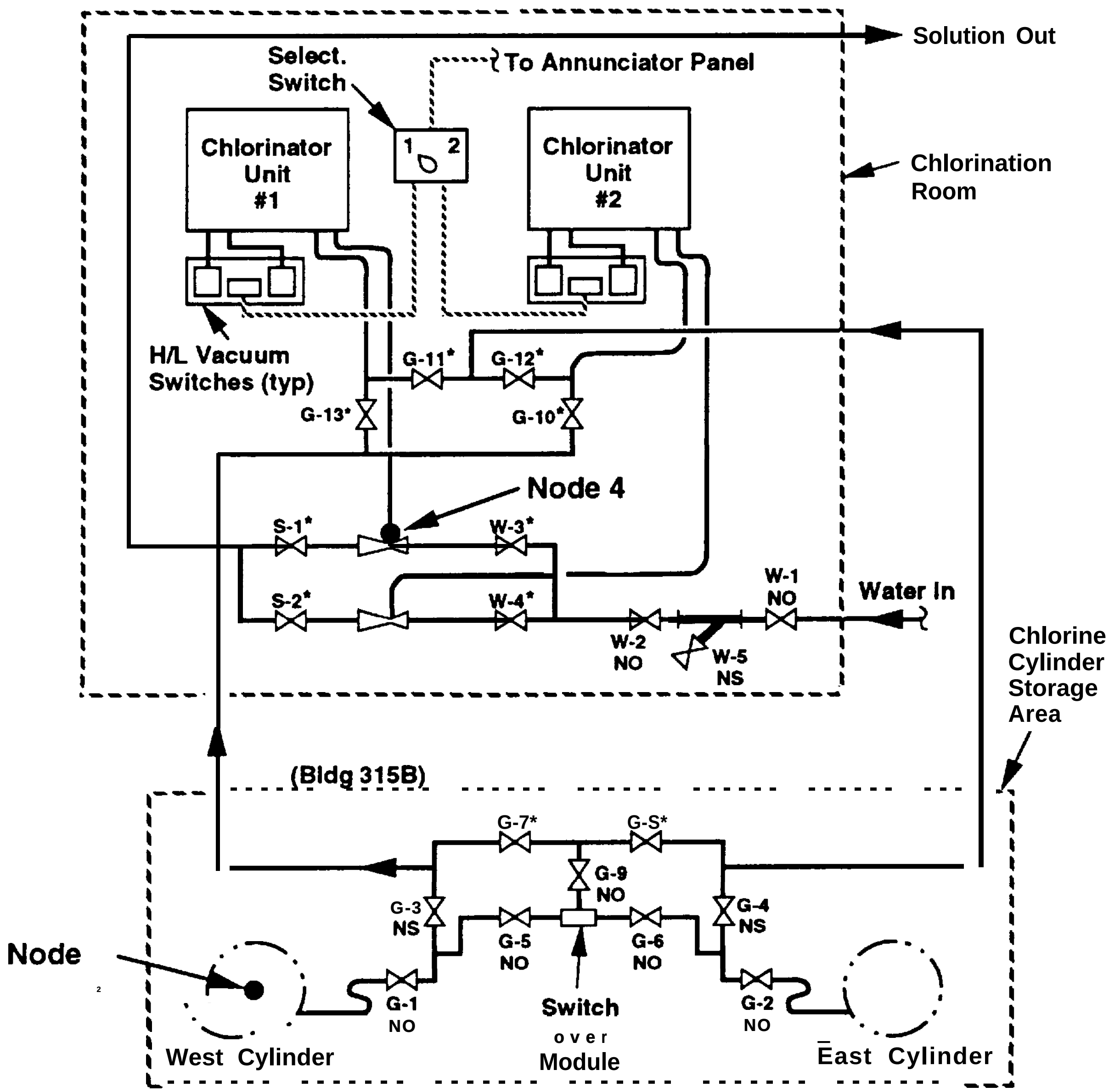
# HAZOP STUDY WORKSHEETS

# APPENDIX B: HAZOP STUDY WORKSHEETS

Two independent chlorination systems are installed at the Hanford 300-Area Water Treatment Facility. These systems can be operated separately or in parallel. Because they are normally operated separately, this HAZOP study assumes only chlorination system #1 is operating, and that valves G-12, G-1 1, G-10, G-8, G-4, G-3, S-2, and W-4 are closed.

The following worksheets document the HAZOP study. The chlorination process was separated into four study nodes. These four nodes are shown on Figure B-1 (Nodes 2 and 4) and Figure B-2 (Nodes 1, 3, and 4). Nodes 5 and 6 cover the procedures for change-out of chlorine cylinders (see Appendix A).

The HAZOP worksheets for the six nodes use HAZOP guide words to determine possible deviations from process design conditions. Causes are described, including positive and negative human factors influences (" +HF" for positive influences and "—HF" for negative influences). Consequences of accident scenarios are estimated qualitatively for each process deviation. Protection and mitigating factors are described, including positive and negative human factors influences. The action/comment column includes both action items and justifications for no further action.




**Notes:**

* - Position depends on which chlorinator or cylinder and/or chloine supply line is in-service

NO - Normally open

NS - Normally shut

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**Figure RI.** Chlorination Process, Study Nodes 2 and 4

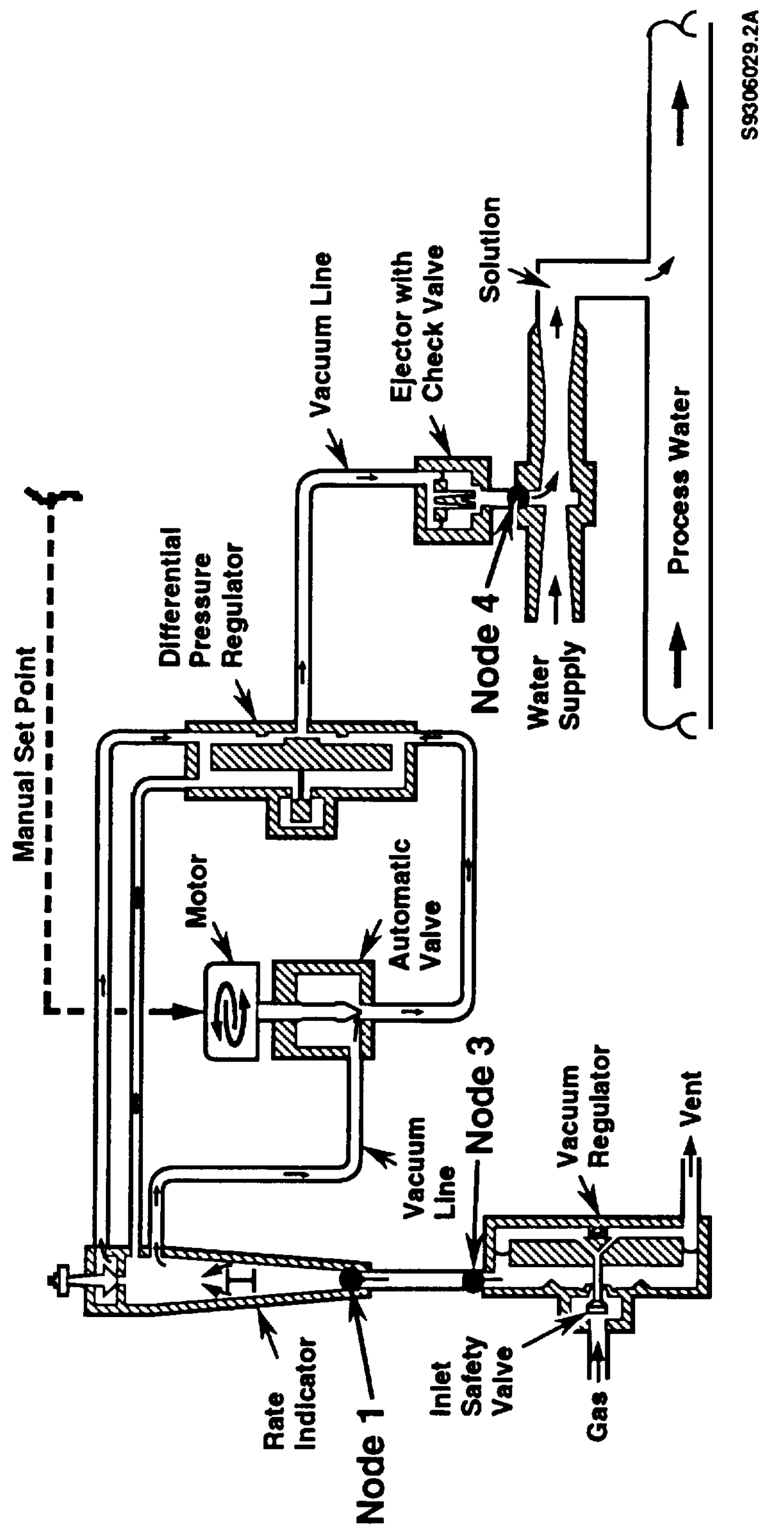


**Figure** B-2. Chlorination Process, Study Nodes 1, 3, and 4

| | | | |
|---|---|---|---|
| PLANT/OPERATION: | Water Treatment Facility / Chlorination Process | REVIEW DATE: | 5/18/93 |
| LINE/VESSEL/NODE: | Node 1 | DRAWING NO.: | Automatic Gas Feed System (Figure B-2) |
| DESIGN INTENTION | Transfer $Cl_2$ Vapor to Rotameter 20-60 lbs/day at 26-inch mercury vacuum at 65°F through ambient | REVIEW TEAM: | K. Agee, J. Rude, S. Camp, F. Leverenz, K. Murphy, S. Kanth, D. Ortiz, J. Angyus, P. Pelto, J. Piatt, R. Hansen |

| GUIDE WORD | DEVIATION | CAUSE | CONSEQUENCES | PROTECTION | SCE-NARIO | ACTION / COMMENTS |
|---|---|---|---|---|---|---|
| No | No Flow | Valve closed (G-1, G-5, G-7, G-9, and G-1 3).<br>. Failed closed.<br>. Inadvertently closed,<br>[-HF: valves located dose to each other \| +HF: flow directions indicated by valve position; valve handles different.]<br>Poly line crimped by activity (e.g., maintenance) in area.<br><br>Screen blocked in regulator on cylinder. | Decreased $Cl_2$ residual in water, violates state code (WAC 246-290). (Takes 1-2 hours to occur.)<br><br>If continued undetected, a bacterial problem could result with illness across the site (within a day). | 1) Automatic switch-over if the valves G-1 and G-5 are closed.<br>2) High vacuum alarm; the operator diagnoses and restores the system if possible.<br>[-HF: many potential causes for this dorm; no procedures for diagnosis \| + HF: time for diagnosis is long; rotameter flow indication aids diagnosis.]<br>3) Low $Cl_2$ residual during surveillance.<br>a) The filter plant is checked every 2 hrs.<br>b) The tour operator checks around the grid (at 12 points/shift).<br>[-HF: operator normally adjusts $Cl_2$ flow via controller, could try to adjust for low $Cl_2$ without noticing rotameter is at no flow \| + HF: several checks by different operators before consequence occurs.]<br>Mitigation: Restrict usage of potable water when low $Cl_2$ is detected, | 1-1 | Sufficient protection. |
| More | More flow | No causes in this segment. | | | 1-2 | |
| Less | Less flow | Valves partially closed (same valves as #1-1). | Same as #1-1 (no flow), except it would take longer. | Same as Protection in #1 -1, 1 ) and 2) (if vacuum from restricted flow is high enough), and 3). | 1-3 | Protection sufficient. |

| | | | |
|---|---|---|---|
| PLANT /OPERATION: | Water Treatment Facility / Chlorination Process | REVIEW DATE: | 5/1 8193 |
| LINE/VESSEL/NODE: | Node 1 | DRAWING NO.: | Automatic Gas Feed System (Figure B-2) |
| DESIGN INTENTION: | Transfer $Cl_2$ Vapor to Rotameter 20-60 lbs/day at 26-inch mercury vacuum at 65°F through ambient | REVIEW TEAM: | K. Agee, J. Rude, S. Camp, F. Leverenz, K. Murphy, S. Kanth, D. Ortiz, J. Angyus, P. Pelto, J. Piatt, R. Hansen |

| GUIDE WORD | DEVIATION | CAUSE | CONSEQUENCES | PROTECTION | SCE-NARIO | ACTION / COMMENTS |
|---|---|---|---|---|---|---|
| Reverse | Reverse flow | Valve S-1 closed.<br>. Failed closed.<br>. Inadvertently closed,<br>[—HF: valves located close to eech other] + HF: flow direction indicated by valve position; valve handles different.] | Water enters the chlorine vapor system with damage to equipment and seals and there is potential for leaks later if it is not repaired:<br>• "In" leakage of air when operating ejector<br>• Small "out" leakage of $Cl_2$ when vacuum from ejector is interrupted; minor irritation if staff present. | 1) Check valve at ejector.<br>2) Low vacuum alarm.<br>[—HF: mew potential causes for this alarm; no procedure for diagnosis].<br>3) Same protection as #I-1, 3). | 1-4 | Check on possibility of backflow past rotameter and respond accordingly by modifying administrative procedures. |
| More | High Temperature | No causes in this segment. | | | 1-5 | |
| Less | Low temperature | No causes for temperature low enough to cause a problem. | | | 1-6 | |
| More | High pressure | No causes in this segment. | | | 1-7 | |
| Less | Low pressure | No causes in this segment. | | | 1-8 | |
| As well as | Air into $C1_2$ | Leak in polyethylene tubing/pipe, valve stem, etc,<br>(Replacement of tubing every two years reduces the likelihood of failure. )<br><br>Potential for dissimilar material to thermally expand or contract from temperature extremes. | Low $Cl_2$ for water treatment.<br><br>If continued undetected, a bacterial problem could result with illness across the site. | Check of $Cl_2$ residuals during surveillance may detect.<br>a) The filter plant is checked every 2 hrs.<br>b) The tour operator checks around the grid (at 12 points/shift).<br>[—HF: operator normally adjusts $Cl_2$ flow via controller, could try to adjust for low $Cl_2$ without noticing rotameter is et no flew [+HF: several checks by different operators before consequence occurs.]<br>Mitigation: Restrict usage of potable water when low $C1_2$ is detected. | 1-9 | Consider adding procedures that verify the vacuum holds after system shutdown (to be use when tubing is replaced and chlorinators are changed each month). |

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|---|---|---|---|
| LANT/OPERATION: | Water Treatment Facility / Chlorination Process | REVIEW DATE | 5/1 8/93 |
| INE/VESSEL/NODE: | Node 1 | DRAWING NO.: | Automatic Gas Feed System (Figure B-2) |
| ESIGN INTENTION: | Transfer $Cl_2$ Vapor to Rotameter 20-60 lbs/day at 26-inch mercury vacuum at 65°F through ambient | REVIEW TEAM: | K. Agee, J. Rude, S. Camp, F. Leverenz, K. Murphy, S. Kanth, D. Ortiz, J. Angyus, P. Pelto, J, Piatt, R. Hansen |

| GUIDE WORD | DEVIATION | CAUSE | CONSEQUENCES | PROTECTION | SCE-NARIO | ACTION / COMMENTS |
|---|---|---|---|---|---|---|
| As well as (cont. ) | Air into $Cl_2$ | Leak in polyethylene tubing/pipe, valve stem, etc. (Replacement of tubing every two years reduces the likelihood of failure. )<br><br>Potential for dissimilar material to thermally expand or contract from temperature extremes. | Potential for damage to seals/corrosion from HCl forming due to moisture in air,<br><br>Same as #1-4. | Operator to check rotameter every 2 hrs. Can visually detect air, if familiar with its appearance.<br><br>Vacuum gage on chlorinator may show decrease in vacuum.<br>[—HF: these require operator with enough experience to recognize ● ornewhat subtle indications; • "novice" not likely to detect. I | 1-10 | Minor consequences. |
| | | Leak in system after replacement of tubing.<br>[—HF: no procedure written for replacement of tubing, or system integrity verification after replacement.] | Same as #l-9 and #l-IO. | Same as #l-9 and #1-10. | 1-11 | Same as #l-9 and #1-10. |
| Part of | No meaningful deviations | | | | | |

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|---|---|---|---|
| PLANT/OPERATION: | Water Treatment Facility / Chlorination Process | REVIEW DATE | 5/1 8193 |
| LINE/VESSEL/NODE: | Node 1 | DRAWING NO.: | Automatic Gas Feed System (Figure B-2) |
| DESIGN INTENTION: | Transfer $Cl_2$ Vapor to Rotameter 20-60 lbs/day at 26-inch mercury vacuum at 65°F through ambient | REVIEW TEAM: | K. Agee, J. Rude, S. Camp, F. Leverenz, K. Murphy, S. Kanth, D. Ortiz, J. Angyus, P, Pelto, J. Piatt, R. Hansen |

| GUIDE WORD | DEVIATION | CAUSE | CONSEQUENCES | PROTECTION | SCE-NARIO | ACTION / COMMENTS |
|---|---|---|---|---|---|---|
| Other than | Air into ejector | Line break (either poly break or schedule-80 steel break inside or outside of building). Maintenance activity could be the cause of failure, especially poly. | Loss of $Cl_2$ to water treatment (see #1-1 ). | 1) Low vacuum alarm, may have $Cl_2$ alarm; the operator diagnoses and switches to alternate supply. [—HF: many potential causes for this alarm; no procedures for diagnosis. 2) Cl residual checks (See #7-1, Protection 3). | 1-12 | Low likelihood. |
| | | | $Cl_2$ release (up to 3/8-inch release). Potential for injuries and fatalities near 315 Building and neighboring buildings. | Regulator shuts off on loss of vacuum.<br><br>**Mitigation: $Cl_2$ alarm (local and remote). Site-wide** emergency response (alarm designed for leaks inside building). "Chlorinator trouble alarm" (31 5 common alarm) with tour operator response. | 1-13 | Low likelihood. Cause and sufficient protection.<br><br>Verify that the adjacent buildings have received information on chlorine in their HAZCOM program. |

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| LANT/OPERATION: | Water Treatment Facility / Chlorination Process | REVIEW DATE: | 5/1 9193 |
| INE/VESSEL/NODE: | Node 2 | DRAWING NO.: | Chlorination Process Flow Diagram (Figure B-1 ) |
| ESIGN INTENTION: | Storage cylinder provides $Cl_2$ gas to regulator at 65°F to ambient, approximately 75 psig to 150 psig (at 11O"F); 20-60 lbs CIZ/day. | REVIEW TEAM: | F. Leverenz, S. Camp, J. Rude, K. Agee, S. Kanth, K. Murphy, D. Ortiz, J. Angyus, R. Hansen |

| GUIDE WORD | DEVIATION | CAUSE | CONSEQUENCES | PROTECTION | SCE-NARIO | ACTIONS/COMMENTS |
|---|---|---|---|---|---|---|
| No | No $Cl_2$ provided | Tank is empty. | Same as #l-1. | Same as #1-1 and weight check. | 2-1 | Same as #l-1. |
| | | Tank valve is closed. | Same as #l-1. | Same as #l-1. | 2-2 | Same as #l-l. |
| | | Internal tank tubes are plugged/defective (blocked). | Same as #l-1. | Same as #l-1. | 2-3 | Same as #l-1. |
| More | More $Cl_2$ provided | No causes. | | | | |
| Less | Less $Cl_2$ provided | Valve partially closed [—HF: valve does not readily indicate amount open.] Internal tank tubes partially plugged. | Same as #2-2 and 2-3 except takes longer to "ccur" | Same as #2-2 and 2-3. | 2-4 | Same as #2-2 and 2-3. |
| More | High temperature | Heater fails "on" during summer heat. | If the temperature is greater than 160° F, the fusible link may release resulting in a $Cl_2$ release. Potential for injuries and fatalities near the 315 Building and neighboring buildings. | Tour operator notices high temperature in room during 2-hour check. [ + HF: operator would likely note temperature of 160" F in building.] Mitigation: Same as #1 -13; cylinder repair kit to reduce size of release. | 2-5 | Calculate temperature based on heat input versus heat loss for this scenario. Base further recommendation items on the results, |

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|---|---|---|---|
| PLANT/OPERATION | Water Treatment Facility / Chlorination Process | REVIEW DATE: | 5/1 9193 |
| LINE/VESSEL/NODE: | Node 2 | DRAWING NO.: | Chlorination Process Flow Diagram (Figure B-1 ) |
| DESIGN INTENTION: | Storage cylinder provides $Cl_2$ gas to regulator at 65°F to ambient, approximately 75 psig to 150 psig (at 11 O"F); 20-60 lbs $Cl_2$/day. | REVIEW TEAM: | F. Leverenz, S, Camp, J. Rude, K. Agee, S. Kanth, K. Murphy, D. Ortiz, J. Angyus, R. Hansen |

| GUIDE WORD | DEVIATION | CAUSE | CONSEQUENCES | PROTECTION | SCE-NARIO | ACTIONS / COMMENTS |
|---|---|---|---|---|---|---|
| More [cont.] | | Fire<br><br>The following reduces the likelihood of a fire:<br>• Internal fire: no combustible or flammable materials are stored in the building,<br>• External fire: there are no likely fire sources.<br>• Housekeeping procedures are used to prevent combustible or flammable materials from entering the building. | If fusible plug(s) work, release will occur via plug, If not, a BLEVE could result,<br><br>Same as #2-5. | None. | 2-6 | Fire is very unlikely. |
| Less | Low temperature | Heater fails in the winter/cold weather, | Potential reduction in $C1_2$ feed rate; no significant consequence, | | 2-7 | Minor consequences. |
| More | High Pressure | Cylinder is received overfilled. | Unknown | Check cylinder weight against the weight of a properly filled chlorine cylinder.<br>[—HF: procedure requires operator to 'zero' weight for new cylinder; may not notice overweight.] | 2-8 | Check pressure potential from chlorine cylinder and the system (regulator) response. Determine whether the fusible plug will open with high pressure. |
| Less | Low pressure | Covered under low temperature (#2-7); no additional causes related to hazards. | | | 2-9 | |
| As well as | Other material added | $C1_2$ contaminated. | Unknown | | 2-1o | Check with vendor regarding possible contamination material for scenarios 2-10 and 2-11. Take appropriate recommendation/action. |

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| PLANT / OPERATION: | Water Treatment Facility / Chlorination Process | REVIEW DATE | 5/1 9193 |
| LINE/VESSEL /NODE | Node 2 | DRAWING NO.: | Chlorination Process Flow Diagram (Figure B-1 ) |
| DESIGN INTENTION: | Storage cylinder provides $Cl_2$ gas to regulator at 65°F to ambient, approximately 75 psig to 150 psig (at 11 O“F); 20-60 lbs $Cl_2$/day. | REVIEW TEAM: | F. Leverenz, S. Camp, J. Rude, K. Agee, S. Kanth, K. Murphy, D. Ortiz, J. Angyus, R, Hansen |

| GUIDE WORD | DEVIATION | CAUSE | CONSEQUENCES | PROTECTION | SCE-NARIO | ACTIONS/COMMENTS |
|---|---|---|---|---|---|---|
| Other than | Another material loaded | Cylinder contains something other than chlorine (e. g., sulfur dioxide uses same size container), | Unknown | | 2-11 | See above. |
| Part of | No meaningful deviations | | | | | |

Hazard and Operability Study Worksheet

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| PLANT/OPERATION: | Water Treatment Facility/Chlorination Process | REVIEW DATE: | 5/1 9193 |
| LINE/VESSEL/NODE: | Node 3 | DRAWING NO.: | Automatic Gas Feed System (Figure B-2) |
| DESIGN INTENTION | Provide $Cl_2$ from storage cylinder to vacuum line at 25 inches of Hg at 65°F to ambient with 20-60 lb./day. | REVIEW TEAM: | F. Leverenz, S. Camp, J. Rude, K. Agee, S. Kanth, K. Murphy, D. Ortiz, Joe Angyus, R. Hansen |

| GUIDE WORD | DEVIATION | CAUSE | CONSEQUENCES | PROTECTION | SCE-NARIO | ACTIONS / COMMENTS |
|---|---|---|---|---|---|---|
| No | No flow | Broken diaphragm, stuck open relief valve, or leak in vacuum side of regulator occurs. | Loss of $Cl_2$ flow (same as #1-12). | Same as #1-9. | 3-1 | Consider #1 -9 recommendation; would need to close the $Cl_2$ cylinder block valve. |
| More | More flow | Regulator fails open. | Release of $Cl_2$ through the relief valve and vent (same as #1-13). Potential for injuries/fatalities near the 315 Building and neighboring buildings. | None. Mitigation: $Cl_2$ alarm (local and remote). Site-wide emergency response (alarm designed for leaks inside building). "Chlorinator trouble alarm" (31 5 common alarm) with tour operator response. | 3-2 | The cause seems to have a low likelihood. The vendor should be contacted to determine the failure experience (corrosion, water, etc. ). If cause seems more likely after investigation, controls such as remote shutoff at $Cl_2$ cylinder (and power fail-safe] should be considered. |
| Less | Low flow | Regulator doesn't open far enough. | Same as #2-4, | Same as #2-4 . | 3-3 | Same as #2-4. |
| Reverse | Reverse flow | No causes in this segment. | | | 3-4 | |
| | | | | | | |
| More | High temperature | No causes this segment, | | | 3-5 | |
| Less | Low temperature | No causes this segment. | | | 3-6 | |
| More | High pressure | No additional causes (see 3-2). | | | 3-7 | |
| Low | Low pressure | No additional causes (see 3-3). | | | 3-8 | |
| Part of | No meaningful deviation this segment | | | | 3-9 | |

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| **PLANT/OPERATION:** | Water Treatment Facility / Chlorination Process | **REVIEW DATE** | 5/1 9193 |
| **LINE/VESSEL/NODE:** | Node 3 | **DRAWING NO.:** | Automatic Gas Feed System (Figure B-2) |
| **DESIGN INTENTION** | Provide $Cl_2$ from storage cylinder to vacuum line at 25 inches of Hg at 65°F to ambient with 20-60 lb./day. | **REVIEW TEAM:** | F. Leverenz, S. Camp, J. Rude, K. Agee, S. Kanth, K. Murphy, D. Ortiz, Joe Angyus, R. Hansen |

| GUIDE WORD | DEVIATION | CAUSE | CONSEQUENCES | PROTECTION | SCE-NARIO | ACTIONS /COMMENTS |
|---|---|---|---|---|---|---|
| As well as | Material in the atmospheric side of the regulator | Sand, water, bugs, dust, etc. | Blocked vent line; if an over-pressure event occurs (3-2) the vacuum line could become over-pressured; the vacuum line may not hold under pressure (same as #1-13). | Vent screen will protect somewhat (same as xl-13). | 3-10 | Verify that the screen is in place. |

**PLANT/OPERATION:** Water Treatment Facility / Chlorination Process

**LINE/VESSEL/NODE:** Node 4

**DESIGN INTENTION:** Provid~~ to ejector at 25 inches of Hg, vacuum, 20-60 lb/day, 65°F to ambient

**REVIEW DATE:** 5/19/93

**DRAWING NO.:** Automatic Gas Feed System and Chlorination Process Flow Diagram (Figures B-1 and B-2)

**REVIEW TEAM** F. Leverenz, S. Camp, J. Rude, K. Agee, S. Kanth, K. Murphy, D. Ortiz, Joe Angyus, R. Hansen

| GUIDE WORD | DEVIATION | CAUSE | CONSEQUENCES | PROTECTION | SCE-NARIO | ACTIONS/COMMENTS |
|---|---|---|---|---|---|---|
| No | No flow | Motor-controlled rate valve closed.<br>. Failed closed.<br>• Operator closes rate control valve inadvertently.<br>[+ HF: up/down" key pad with digital readout display of position.]<br>Ejector check valve failed closed.<br><br>Valves plugged by dirt. | Same as #I-1. | Same as #I-1. | 4-1 | Protection sufficient, |
| More | More flow | Rotameter opened too far.<br>. Rate valve opened too far.<br>[–HF: possible error in residual • ample or calculation<br>[+HF: "up/down. key pad with digital readout display of position.]<br>. Manual rate valve also opened.<br>[-HF: confusion of which control to use.]<br>• Operator does not reset to a lower value when the demand decreases.<br>[–HF: operators depend on memory to complete actions.1<br>. PLC controller fails. | Objectionable tastes/vapors in the water. | 1) Operator checks visual flow on rotameter at tank.<br>[–HF: operator usually relies on digital is not likely used to using rotameter flow indication.]<br>2) Surveillance of "residuals" (see Protection 3) for #1-1. | 4-2 | Minor consequence. |

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| PLANT /OPERATION: | Water Treatment Facility / Chlorination Process | REVIEW DATE | 5/19193 |
| LINE/VESSEL /NODE: | Node 4 | DRAWING NO.: | Automatic Gas Feed System and Chlorination Process Flow Diagram (Figures B-1 and B-2) |
| DESIGN INTENTION: | Provide $Cl_2$ to ejector at 25 inches of Hg, vacuum, 20-60 lb/day, 65°F to ambient | REVIEW TEAM: | F. Leverenz, S. Camp, J. Rude, K. Agee, S. Kanth, K. Murphy, D. Ortiz, Joe Angyus, R. Hansen |

| GUIDE WORD | DEVIATION | CAUSE | CONSEQUENCES | PROTECTION | SCE-NARIO | ACTIONS /COMMENTS |
|---|---|---|---|---|---|---|
| Less | Less flow | Plugged ejector.<br><br>Rota meter closed too much,<br>• Rate valve not opened enough.<br>[-HF: possible error m residual sample or calculation<br>] +HF: "up/down" key pad with digital readout display of position].<br>• Operator does not reset to a higher value when the demand increases.<br>[—HF: operators depend on memory to complete actions.]<br>• PLC controller fails. | Same as #1-3. | Same as #l -3. | 4-3 | Sufficient protection. |
| More/less | High or low pressure | Differential pressure regulator. | Unknown | | 4-4 | How the differential pressure regulator operates is unknown. The valve's operation should be checked and the potential for a pressure deviation should be assessed. |

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| LANT/OPERATION: | Water Treatment Facility / Chlorination Process | REVIEW DATE | 5/1 9/93 |
| INE/VESSEL/NODE: | Node 4 | DRAWN(3 NO.: | Automatic Gas Feed System and Chlorination Process Flow Diagram (Figures B-1 and B-2) |
| ESIGN INTENTION: | Provide $Cl_2$ to ejector at 25 inches of Hg, vacuum, 20-60 lb/day, 65°F to ambient | REVIEW TEAM: | F. Leverenz, S. Camp, J. Rude, K. Agee, S. Kanth, K. Murphy, D. Ortiz, Joe Angyus, R. Hansen |

| GUIDE WORD | DEVIATION | CAUSE | CONSEQUENCES | PROTECTION | SCE-NARIO | ACTIONS/COMMENTS |
|---|---|---|---|---|---|---|
| More | High temperature | Chlorinator heater fails "on" in summer, | Possible water pipe rupture if the temperature exceeds the PVC's strength, Small chlorine release (no health effects expected), | None. | 4-5 | Minor consequences. |
| | | | PLC operational limits. The PLC could malfunction if temperature is too high (see less/more flow scenario, #I-2 and #I-3). | Same as #I-2 and #1 -3. | 4-6 | (PLC operating range: 14° F-122° F,)<br><br>Protection sufficient (#1 -3) and minor consequences (#1 -2). |
| Less | Low temperature | Heater fails during cold weather [winter). | Out-of-service water pipe breaks (water freezes in the line). | The operator's 2-hour check of the facility.<br>[-HF: operator may not note cracked/broken line while it is still frozen \| + HF: operator will likely note temperature of building is low.] | 4-7 | Minor consequences. |
| | | | Safety shower and eye wash freezes. There is potential for more serious injury if an incident occurs during unavailability. | Safety shower and eye wash lines are heat traced. | 4-8 | Low likelihood that an incident occurs the same time freezing occurs. |
| Part of | No meaningful deviation | | | | | |
| As well as | Air into chlorine vacuum line | Leak in the line/fittings: potential for dissimilar material to thermally expand or contract from temperature extremes. | Same as #I-9 and #1-10. | Operator check of chlorine residuals, (Same as Protection 3 of #1 -1). | 4-9 | Same as #I-9 and #1-10. |
| Reverse | Reverse flow | Already covered "#1-4. | | | 4-10 | Same as #1-4. |

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| PLANT/OPERATION: | Water Treatment Facility / Chlorination Process | REVIEW DATE: | 5/1 9/93 |
| LINE/VESSEL/NODE: | Node 4 | DRAWING NO.: | Automatic Gas Feed System and Chlorination Process Flow Diagram (Figures B-1 and B-2) |
| DESIGN INTENTION: | Provide $Cl_2$ to ejector at 25 inches of Hg, vacuum, 20-60 lb/day, 65°F to ambient | REVIEW TEAM: | F. Leverenz, S. Camp, J. Rude, K. Agee, S. Kanth, K. Murphy, D. Ortiz, Joe Angyus, R. Hansen |

| GUIDE WORD | DEVIATION | CAUSE | CONSEQUENCES | PROTECTION | SCE-NARIO | ACTIONS / COMMENTS |
|---|---|---|---|---|---|---|
| Other than | Air only into injector | Line break in vacuum line. | Same as $1-12. | Same as #1-12. | 4-11 | Same as #1-12. |
| None | No level | Chlorine tank failure (e.g., structural flaw). | Release of contents. Potential for injury and fatalities of staff in the surrounding area. | None,<br><br>Mitigation: $Cl_2$ alarm (local and remote). Site-wide emergency response (alarm designed for leaks inside building), "Chlorinator trouble alarm" (31 5 common alarm) with tour operator response. | 4-12 | Low likelihood. |
| No | Loss of utility (off-site power) | Loss of electric power; water pumps discontinue operating.<br>(Loss of vacuum to chlorinator). | $Cl_2$ is release through the vent,<br><br>$Cl_2$ contacts back flow preventers with potential damage to equipment.<br><br>Up to 3/8-inch leak with potential for injuries and fatalities near 315 Building and neighboring buildings. | Regulator safety valve,<br><br>Mitigation: (Same as #4-12). | 4-13 | Note: the detector has battery backup and an alarm on standby power,<br><br>Verify that the monthly PM includes checking the backup battery for the chlorine alarm.<br><br>Note: there are plans to put water pumps on standby power, which will make this "cause" less likely, |

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| PLANT/OPERATION: Water Treatment Facility / Procedures | REVIEW DATE 5/20193 |
| LINE/VESSEL/NODE: Node 5 | DRAWING NO.: Procedures for the Change-out of Chlorine Cylinders (see Appendix A) |
| DESIGN INTENTION: Removing Empty Chlorine Cylinder (west cylinder) | REVIEW TEAM: F. Leverenz, S. Camp, J. Rude, K. Agee, S. Kanth, K. Murphy, D. Ortiz, J. Angyus, J. Piatt, R. Hansen |
| Guide Words without meaningful deviations have been omitted from this table. | |

| GUIDE WORD | DEVIATION | CAUSE | CONSEQUENCES | PROTECTION | SCE-NARIO | ACTIONS/COMMENTS |
|---|---|---|---|---|---|---|
| | (1) Notify the 384 Powerhouse and the Hanford Fire Department that the chlorine cylinder change-out is in progress. | | | | | |
| No | Skip step | Supervisor does not notify. | May increase response time/readiness of personnel because of no advanced warning. False response upon disconnect of regulator resulting in $C1_2$ alarm (Step 1 1)0 | None, | 5-1 | Minor consequences. |
| | (2) Start the 3 15B Building vent fan and operate it for 3 minutes before entering. Maintain the vent fan continuously. | | | | | |
| No/less | Skip step. (Operate less than 3 min. ) | The $C1_2$ plant operator does not start the fan, | Possible exposure if a leak exists and the detector failed,<br>Possible irritation with low likelihood of injury. | Detector malfunction alarm alerts operator that detector has failed. [—HF: operator may proceed and assume no $Cl_2$ is present.] | 5-2 | Low likelihood. |
| | (3) Enter through the walk-through door. | | | | | |
| | No meaningful deviation | | | | 5-3 | |

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| LANT/OPERATION: | Water Treatment Facility / Procedures | REVIEW DATE | 5/20/93 |
| INE/VESSEL/NODE: | Node 5 | DRAWING NO.: | Procedures for the Change-out of Chlorine Cylinders (see Appendix A) |
| ESIGN INTENTION: | Removing Empty Chlorine Cylinder (west cylinder) | REVIEW TEAM: | F. Leverenz, S. Camp, J. Rude, K. Agee, S. Kanth, K. Murphy, D. Ortiz, J. Angyus, J. Piatt, R. Hansen |

Guide Words without meaningful deviations have been omitted from this table.

| GUIDE WORD | DEVIATION | CAUSE | CONSEQUENCES | PROTECTION | SCE-NARIO | ACTIONS/COMMENTS |
|---|---|---|---|---|---|---|
| | (4) Identify the empty cylinder by its weight, and verify the indication of no flow on the cylinder regulator. | | | | | |
| No | Skip step | $Cl_2$ plant operator does not check cylinder weight and or indication of no flow. | f the wrong cylinder is selected, there is loss of $Cl_2$ o the chlorinator (same as #1-1). | 1) At Step 5 an alarm is received on loss of vacuum. [—HF: may assume this is a normal alarm for change-out of cylinder.] 2) Hoisting and rigging crew notices that tank is heavier than normal. [+HF: crew is experienced in change-out of cylinder.] 3) At Step 9 alarm does not clear. [—HF: 'reverse' indication is more likely to be misinterpreted.] | 5-4 | diner consequences. |
| | | | Release of contents of full cylinder at Step 11. Injury/potential fatality of the plant operator. Injury/fatality potential in nearby buildings. | 1) At Step 5 cylinder valve is closed. 2) At Step 8 the chlorinator flow is checked. Actuated alarm has been checked. 3) At Step 11 plant operator checks for leaks when removing regulator [—HF: this step requires judgement on how to remove to detect that tank is still open.] Mitigation: personal protective equipment. Mitigation: observer radios HAZMAT team; emergency response initiated. | 5-5 | Protection sufficient. |

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| PLANT/OPERATION: | Water Treatment Facility / Procedures | REVIEW DATE: | 5/20/93 |
| LINE/VESSEL/NODE: | Node 5 | DRAWING NO.: | Procedures for the Change-out of Chlorine Cylinders (see Appendix A) |
| DESIGN INTENTION: | Removing Empty Chlorine Cylinder (west cylinder) | REVIEW TEAM: | F. Leverenz, S. Camp, J. Rude, K. Agee, S. Kanth, K. Murphy, D. Ortiz, J. Angyus, J. Piatt, R. Hansen |

Guide Words without meaningful deviations have been omitted from this table.

| GUIDE WORD | DEVIATION | CAUSE | CONSEQUENCES | PROTECTION | SCE-NARIO | ACTIONS /COMMENTS |
|---|---|---|---|---|---|---|
| | (5) Close the angle (root) valve on the chlorine cylinder. | | | | | |
| No | Skip step | $Cl_2$ plant operator does not close the valve. | Release of the remaining cylinder contents at Step 11.<br><br>Injury to plant operator.<br><br>Injury to staff in nearby buildings. | 1 ) Step 8 chlorinator flow checked/alarm actuated.<br>2) Step 11 slowly disconnect regulator and check for leaks.<br><br>Mitigation: personnel protective equipment.<br><br>Mitigation: observer radios hazmat team; emergency response initiated. | 5-6 | Sufficient protection. |
| Less | Valve partially closed. | Plant operator does not close the valve completely. [–HF: valve provides no indication of position.] | Lesser consequence than #5-6.<br><br>Injury to plant operator. | At Step 11 check for leaks at disconnect. [–HF: • MW as #5-5, 3).]<br><br>Mitigation: Personal protection equipment. | 5-7 | Sufficient protection. |
| Reverse | Valve opened all the way | Plant operator opens rather than closes the valve. [–HF: valve provides no indication of position, and full open 'feels" like full closed.] | Same as #5-6. | Same as #5-6. | 5-8 | Sufficient protection. |
| | (6) Isolate the automatic switch-over valve. (Close valves G5, G6, and G9). | | | | | |
| No | Skip step | Plant operator skips step. | At Step 11 when disconnect slightly larger release of $Cl_2$.<br><br>Minor irritation. | At Step 8, flow/vacuum alarm check. | 5-9 | Sufficient protection. |

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| PLANT/OPERATION: | Water Treatment Facility / Procedures | REVIEW DATE: | 5120/93 |
| LINE/VESSEL/NODE: | Node 5 | DRAWING NO.: | Procedures for the Change-out of Chlorine Cylinders (see Appendix A) |
| DESIGN INTENTION | Removing Empty Chlorine Cylinder (west cylinder) | REVIEW TEAM: | F. Leverenz, S. Camp, J. Rude, K. Agee, S. Kanth, K. Murphy, D. Ortiz, J. Angyus, J. Piatt, R. Hansen |
| Guide Words without meaningful deviations have been omitted from this table. | | | |

| GUIDE WORD | DEVIATION | CAUSE | CONSEQUENCES | PROTECTION | SCE-NARIO | ACTIONS/COMMENTS |
|---|---|---|---|---|---|---|
| | (7) Verify that valves G8 and G4 are closed. | | | | | |
| No | Skip step | Plant operator skips this step. | No consequences. | | 5-1o | No consequences. |
| | (8) Verify that valve G1 is open, and open valve G3. Wait 2 minutes and verify that there is no flow at the chlorinator in service. Verify that the high-vacuum alarm is actuated. | | | | | |
| No | Skips step | Plant operator skips this step. | Same as #5-9. | 1 ) Slow disconnect and leak check at Step 11. [—HF: see #5-5, 3).]<br><br>Mitigation: personal protective equipment. | 5-11 | Sufficient protection. |
| Less | Less time | Plant operator proceeds without waiting 2 min. | Lesser consequence than #5-n, | 1 ) Flow check at chlorinator.<br>2) High vacuum alarm at Step 11,<br>3) Slow disconnect and leak check at Step 11. [—HF: see #5-5, 3).]<br><br>Mitigation: personal protective equipment, | 5-12 | Sufficient protection. |
| Part of | Skips check on step | Plant operator skips “checks” of vacuum alarm and flow. | Loss of protection for this step and for previous steps, | None. | 5-13 | No direct consequence. |
| | Skips opening G3 | Plant operator does not open G3. | Same as #5-11. | Same as #5-12. | 5-14 | Sufficient protection. |

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| 'IANT/OPERATION: | Water Treatment Facility / Procedures | REVIEW DATE: | 5/20/93 |
| .INE/VESSEL/NODE: | Node 5 | DRAWING NO.: | Procedures for the Change-out of Chlorine Cylinders (see Appendix A) |
| )ESIGN INTENTION | Removing Empty Chlorine Cylinder (west cylinder) | REVIEW TEAM: | F, Leverenz, S. Camp, J. Rude, K. Agee, S. Kanth, K. Murphy, D. Ortiz, J. Angyus, J. Piatt, R. Hansen |

Guide Words without meaningful deviations have been omitted from this table.

| GUIDE WORD | DEVIATION | CAUSE | CONSEQUENCES | PROTECTION | SCE-NARIO | ACTIONS/COMMENTS |
|---|---|---|---|---|---|---|
| | (9) Close valves G 1 and G3. Open valves G6 and G9, and verify that the high-vacuum alarm clears. | | | | | |
| No | Skips step. | Plant operator skips this step. | Same as #1-12 when line opened at Step 11. | Low vacuum alarm occurs at Step 11. | 5-15 | Minor consequence, |
| 'art of | Skips closing valves. | Plant operator does not close G1 and G3. [ -HF: valves close together and easy to confuse.] | At Step 11 air is introduced into the system, reducing chlorination. | Low vacuum alarm occurs at Step 11. | 5-16 | Minor consequence. |
| | Skips opening valves. | Plant operator does not open G6 and G9. [—HF: same as #5-16.] | Same as #I-1. | 1 ) High vacuum alarm does not clear.<br>2) Cl residual checks (see #/-I, Protection 3). | 5-17 | Protection sufficient, |
| Other than | Wrong valves are opened. | Plant operator opens G5 and G9. [—HF: ● an% as #5-16.] | Same as #5-15. | Same as #5-15. | 5-18 | Minor consequence. |
| | (lo) Chlorine serviceman dons the facemask respirator, and operator dons self-contained breathing apparatus (SCBA). Then they verify the operation of the personal protective equipment. | | | | | |
| No | Skip step | Neglect to wear the personal protective equipment. | Loss of protection for scenarios where needed. | Observer reminds serviceman of need for personal protective equipment, | 5-20 | No direct consequence. |

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|---|---|---|---|
| PLANT / OPERATION: | Water Treatment Facility / Procedures | REVIEW DATE: | 5/20/93 |
| LINE/VESSEL/NODE: | Node 5 | DRAWING NO.: | Procedures for the Change-out of Chlorine Cylinders (see Appendix A) |
| DESIGN INTENTION: | Removing Empty Chlorine Cylinder (west cylinder) | REVIEW TEAM: | F. Leverenz, S. Camp, J. Rude, K. Agee, S. Kanth, K. Murphy, D. Ortiz, J. Angyus, J. Piatt, R. Hansen |

Guide Words without meaningful deviations have been omitted from this table.

| GUIDE WORD | DEVIATION | CAUSE | CONSEQUENCES | PROTECTION | SCE-NARIO | ACTIONS/COMMENTS |
|---|---|---|---|---|---|---|
| | (11) Slowly disconnect the regulator, check it for leaks, and set it on the floor. | | | | | |
| No | Skip step | Serviceman does not disconnect the regulator. | Hoses could be broken if cylinder is moved at Step 13.<br>Small release; minor irritation, | Observation that regulator is still connected, | 5-21 | Minor consequences. |
| Part of | Skip part of step. | Serviceman does not open slowly while checking for leaks.<br>[–HF: experience required to judge "slowly" and to differentiate between a leak and residual $Cl_2$ in the line.] | Loss of protection in previous scenarios, | None, | 5-22 | No direct consequence. |
| As well as | Unwanted action | Serviceman drops regulator after disconnect. | Damage regulator; possible "cause" for scenario in re-connection. | Serviceman alerts operations supervisor of drop. | 5-23 | No direct consequence. |
| Other than | Wrong cylinder | Serviceman selects the wrong cylinder. | Serviceman disconnects in-use cylinder with release of full cylinder contents (see 5-5).<br><br>Potential for injuries and fatalities near 315 Building and neighboring buildings. | 1 ) Verify tank valves are closed.<br>[-HF: procedure doee not require check of cylinder valve<br>[+HF: serviceman has considerable experience].<br>2) Open slowly with ammonia check.<br>[–HF: see #5-5, 3, Protection.]<br>3) Low vacuum alarm and $Cl_2$ alarm.<br>[–HF: operator may assume thii is normal alarms for disconnect.] | 5-24 | Sufficient protection.<br><br>Existing tagging system to be incorporated into disconnect procedures. |

PLANT/OPERATION: Water Treatment Facility / Procedures
LINE/VESSEL/NODE: Node 5
DESIGN INTENTION: Removing Empty Chlorine Cylinder (west cylinder)
Guide Words without meaningful deviations have been omitted from this table.

REVIEW DATE: 5/20/93
DRAWING NO.: Procedures for the Change-out of Chlorine Cylinders (see Appendix A)
REVIEW TEAM: F. Leverenz, S. Camp, J. Rude, K. Agee, S. Kanth, K. Murphy, D. Ortiz, J. Angyus, J. Piatt, R. Hansen

| GUIDE WORD | DEVIATION | CAUSE | CONSEQUENCES | PROTECTION | SCE-NARIO | ACTIONS / COMMENTS |
|---|---|---|---|---|---|---|
| | (12) Install the cap on the cylinder angle valve, and install the protective hood. | | | | | |
| No | Skip step | Serviceman does not install the cap, | Loss of protection for valves and threads during subsequent handling incidents. | Visual observation when cylinder is moved (Step 13). | 5-25 | Low likelihood. |
| | (13) Position the crane and cylinder truck for loading; open the roll-up door; remove the chocks; and push tha cylinder out to the stops. | | | | | |
| Reverse | Reverse part of step | Trucks are not in place when cylinder rolled out. | Possibility of vehicle impact with the cylinder resulting in release of $C1_2$. Potential injuries in the area. | None. | 5-26 | Low likelihood. |
| | (14) Release the chain binders, and turn the cylinder over to the hoist and rigging crew. | | | | | |
| No | Skip step | Chain binders are not released, | Cannot load cylinder onto the truck; potential damage to the equipment. | Hoist crew notes that the chain is connected, | 5-27 | Minor consequence. |
| | (15) Install the spreader bar, lift the cylinder, and place it on the flatbed truck. | | | | | Note: hoisting and rigging crew has detailed procedure. |
| Part of | Incomplete installation | Partially hooked, | The dropped cylinder is damaged resulting in a $Cl_2$ release. Same as #5-26. | Radio for hazmat support. | 5-28 | Low likelihood. |
| As well as | Unwanted action | Crane operator mishandles the cylinder lift. | Cylinder strikes object. Same as #5-28. | None. | 5-29 | Low likelihood. |
| Part of | Fails during lift | Crane or rigging fails (broken cables, etc.). | Same as #5-28. | Same as #5-28. | 5-30 | Low likelihood. Rigging is certified by non-destructive examination. |

| | | | |
|---|---|---|---|
| PLANT/OPERATION: | Water Treatment Facility / Procedures | REVIEW DATE | 5120193 |
| LINE/VESSEL/NODE: | Node 5 | DRAWING NO.: | Procedures for the Change-out of Chlorine Cylinders (see Appendix A) |
| DESIGN INTENTION: | Removing Empty Chlorine Cylinder (west cylinder) | REVIEW TEAM: | F. Leverenz, S. Camp, J. Rude, K. Agee, S. Kanth, K. Murphy, D. Ortiz, J. Angyus, J. Piatt, R. Hansen |

Guide Words without meaningful deviations have been omitted from this table,

| GUIDE WORD | DEVIATION | CAUSE | CONSEQUENCES | PROTECTION | SCE-NARIO | ACTIONS/COMMENTS |
|---|---|---|---|---|---|---|
| | (16) Secure the cylinder and transport it. | | | | | |
| No | Skip step | Driver does not secure the cylinder. | The cylinder is released during transport (e.g., falls off truck). Potential for cylinder failure, $Cl_2$ release and injuries to people along the route. | None. | 5-31 | Low likelihood. |
| | (17) Close the roll-up door, and exit through the walk-through door. | | | | | |
| No | Skip step | Plant operator does not close the doors. | May compromise effectiveness of $Cl_2$ detectors. | Tour operator surveillance, | 5-32 | Low likelihood. |

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|---|---|
| PLANT/OPERATION: Water Treatment Facility / Procedures | REVIEW DATE: 5/21/93 |
| LINE/VESSEL/NODE: Node 6 | DRAWING NO.: Procedures for the Change-out of Chlorine Cylinders (see Appendix A) |
| DESIGN INTENTION: Install Replacement Chlorine Cylinder (west cylinder) | REVIEW TEAM: F, Leverenz, J. Rude, S, Camp, D. Ortiz, J. Angyus, R. Hansen |
| Guide Words without meaningful deviations have been omitted from this table. | |

| GUIDE WORD | DEVIATION | CAUSE | CONSEQUENCES | PROTECTION | SCE-NARIO | ACTIONS/COMMENTS |
|---|---|---|---|---|---|---|
| | (1) Turn on or verify that the storage room exhaust fan is on. | | | | | Note: Hoisting and rigging crew has detailed procedure. |
| No | Skip step | Plant operator does not turn the fan on. | Loss of prevention for Step 10 (entry of storage building). | Serviceman notes the fan is off before entry and turns it on. (—HF: ● rvicemm works on many different installations and may not think to check the fan.) | 6-1 | Insignificant consequences. |
| | (2) Position the crane for unloading, | | | | | |
| Part of | Mis-positioned | Crane is mis-positioned (would require extreme mis-positioning). | Difficulty in moving cylinder to trolley; may delay replacement. It is possible that the cylinder could be damaged, Possible injuries and fatalities in area if release occurs from damage. | Other crew members, | 6-2 | Low likelihood. Crane has considerable flexibility. |
| | (3) Position the chlorine transport truck for unloading, | | | | | |
| Part of | Mis-positioned | Truck is mis-positioned (would require extreme mis-positioning). | Same as #6-2. | Same as #6-2. | 6-3 | Low likelihood. |

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| PLANT/OPERATION: | Water Treatment Facility / Procedures | REVIEW DATE: | 5/21/93 |
| LINE/VESSEL/NODE | Node 6 | DRAWING NO.: | Procedures for the Change-out of Chlorine Cylinders (see Appendix A) |
| DESIGN INTENTION | Install Replacement Chlorine Cylinder (west cylinder) | REVIEW TEAM: | F. Leverenz, J. Rude, S. Camp, D. Ortiz, J. Angyus, R. Hansen |

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| GUIDE WORD | DEVIATION | CAUSE | CONSEQUENCES | PROTECTION | SCE-NARIO | ACTIONS/COMMENTS |
|---|---|---|---|---|---|---|
| | (4) Verify that tha chlorine cylinder trolley is in position to receive the cylinder. | | | | | |
| Part of | Mis-positioned | Trolley is mis-positioned and no correction occurs, (The worst case is when the trolley is off the track.) | Same as #6-2.<br><br>If it is off the track, it could roll. (The apron or concrete pad is sloped toward parking lot.) It would likely stop when the wheels run off the apron onto the gravel. | Same as #6-2. | 6-4 | Low likelihood, |
| | (5) Release the cylinder binder(s) on the transport vehicle. | | | | | |
| No | Skip step | Driver does not release the binders. | Cannot remove the cylinder, | Hoist and rigging crew notice binder at Step 6. | 6-5 | Minor consequence. |
| Part of | Only one binder in place | Driver only releases one binder. | One end of cylinder moves the other does not, same as #6-5. | Same as #6-5. | 6-6 | Minor consequence. |
| | (6) Install the lifting bar, and lift the cylinder. | | | | | |
| Part of | Incomplete installation | Same as #5-28. | Same as #5-28. | None, | 6-7 | Low likelihood, |
| | (7) Place the cylinder on the trolley. | | | | | |
| Part of | Fails during lift | Crane or rigging fails (broken cables, etc.). | Same as #5-30. | None, | 6-8 | Low likelihood, Rigging is certified by non-destructive examination. |
| As well as | Unwanted action | Crane operator mis-handles lift. | Same as #5-29. | None, | 6-9 | Low likelihood. |

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| **PLANT/OPERATION:** | Water Treatment Facility / Procedures | REVIEW DATE: | 5/21/93 |
| **LINE/VESSEL/NODE:** | Node 6 | **DRAWING** NO.: | Procedures for the Change-out of Chlorine Cylinders (see Appendix A) |
| **DESIGN** INTENTION | Install Replacement Chlorine Cylinder (west cylinder) | REVIEW TEAM: | F. Leverenz, J. Rude, S. Camp, D. Ortiz, J. Angyus, R. Hansen |

Guide Words without meaningful deviations have been omitted from this table.

| GUIDE WORD | DEVIATION | CAUSE | CONSEQUENCES | PROTECTION | SCE-NARIO | ACTIONS / COMMENTS |
|---|---|---|---|---|---|---|
| | (8) Remove the lifting bar, removing it from the immediate area. | | | | | |
| No | Skip step | Bar is not removed. | Delay in the replacement of the cylinder. | None, | 6-10 | Minor consequence. |
| | (9) Secure the cylinder to the trolley with chain binders (2}. | | | | | |
| No | Skip step | Plant operator does not install chain binders. | No consequences except chains dragging as trolley pushed into building. | Sound of dragging chains. | 6-11 | Low likelihood. Primary reason for chain binders as seismic precautions; seismic activity is small (below seismic probability of zone 2). |
| | (lo) Enter the walk-through door, and open the roll-up door. | | | | | |
| | No meaningful deviations | | | | | |
| | (11) Push the trolley and the chlorine cylinder into the building and against the rail stop. Install the wheel chocks. | | | | | |
| No | Skip step | Plant operator does not move the cylinder. | Delay in replacement of cylinder. | Position noted by rest of staff. | 6-12 | Minor consequences. |
| Part of | Part of step skipped | Wheel chocks are not installed. | Precaution (against movement) not in place. | Missing chocks noted by staff during routine checks. [-HF: chocks ore not readily visible as they are under tank.] | 6-13 | No direct consequence. |
| | Not positioned | Plant operator does not push the cylinder (on trolley) in far enough. | When the regulator is installed lines are damaged by stretching. Low or no $Cl_2$ flows to the chlorinator when the cylinder is put in use (see also #I-9). | 1 ) Serviceman notes the position and requires correction. [+HF: position is noted when lines do not readily reach cylinder. ] 2) Step 19 leak check, | 6-14 | Sufficient protection. |

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|---|---|---|---|
| PLANT/OPERATION: | Water Treatment Facility / Procedures | REVIEW DATE: | 5121193 |
| LINE/VESSEL/NODE: | Node 6 | DRAWING NO.: | Procedures for the Change-out of Chlorine Cylinders (see Appendix A) |
| DESIGN INTENTION: | Install Replacement Chlorine Cylinder (west cylinder) | REVIEW TEAM: | F. Leverenz, J. Rude, S. Camp, D. Ortiz, J. Angyus, R. Hansen |

Guide Words without meaningful deviations have been omitted from this table.

| GUIDE WORD | DEVIATION | CAUSE | CONSEQUENCES | PROTECTION | SCE-NARIO | ACTIONS / COMMENTS |
|---|---|---|---|---|---|---|
| | (12) Request the chlorine serviceman to remove the protective hood from the chlorine cylinder. | | | | | |
| No | Skip step | Serviceman does not remove hood. | Delay in replacement. | Noted by staff, | 6-15 | |
| | (13) Observe the position of cylinder angle valves. If the valves are not in vertical alignment, loosen the chain binders and rotate the cylinder to obtain vertical alignment, and then tighten the chain binders. | | | | | |
| No | Skip step | Serviceman does not vertically align the cylinder. [−HF: alignment done by observation of cylinder connections] [+ HF: serviceman has considerable experience with connections.] | Potential to for liquid chlorine to enter the ejector and over chlorinate; potential for $Cl_2$ release from the water.<br><br>Release potential unknown. | | 6-16 | Consult the vendor on this scenario and the expected system response. Estimate the amount of $Cl_2$ release potential. |
| Part of | Part of step | Chains are not tightened after alignment. | No consequence expected. | | 6-17 | No consequence expected. |
| | (14) Chlorine serviceman dons the facemask respirator, and operator dons self-contained breathing apparatus (SCBA). Then they verify the operation of the personal protective equipment. | | | | | |
| No | Skip step | Neglect to wear personal protective equipment. | Loss of protection for scenarios where needed. | | 6-18 | No direct consequence. |
| | (15) Verify that the chlorine cylinder gas angle valve is closed. | | | | | |
| No | Skip step | Serviceman does not verify it is closed. | At Step 16, $Cl_2$ is released when the cap is removed if the valve is not fully closed.<br><br>Same as #5-5. | At Step 16, the cap is opened slowly while checking for leaks. [+ HF: serviceman experienced with importance of this check.]<br><br>Same mitigation as #5-5. | 6-19 | Sufficient protection. |

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|---|---|---|---|
| PLANT / OPERATION: | Water Treatment Facility / Procedures | REVIEW DATE: | 5/21 /93 |
| LINE/VESSEL /NODE: | Node 6 | DRAWING NO.: | Procedures for the Change-out of Chlorine Cylinders (see Appendix A) |
| DESIGN INTENTION: | Install Replacement Chlorine Cylinder (west cylinder) | REVIEW TEAM: | F. Leverenz, J. Rude, S. Camp, D. Ortiz, J. Angyus, R. Hansen |

(Guide Words without meaningful deviations have been omitted from this table.

| GUIDE WORD | DEVIATION | CAUSE | CONSEQUENCES | PROTECTION | SCE-NARIO | ACTIONS / COMMENTS |
|---|---|---|---|---|---|---|
| | **(16) Check for leaks while slowly removing the protective cap from the cylinder gas angle valve.** | | | | | |
| More/ Part of | Too fast/not check | Serviceman opens the cap too quickly or does not check for leaks. [+ HF: serviceman experienced with importance of this check. ] | If valve is open or leaking, the release of $Cl_2$ is possible (amount depends on valve opening). Same as #5-5. | Mitigation: $Cl_2$ alarm with emergency response and same mitigation as #5-5. | 6-20 | Cause unlikely. |
| | **(17) Clean the sealing surface of the gas angle valve and the vacuum regulator. Visually inspect the regulator valve body for damage.** | | | | | |
| No | Skip step | Serviceman does not clean/check sealing surface of angle valve or vacuum regulator, | Possible seal leak at Step 18 or leak from damaged regulator, $Cl_2$ release at Step 19 same as #5-5, | Leak check at Step 19. [ + HF: serviceman experienced with importance of this check.] Mitigation: $Cl_2$ alarm with emergency response and same mitigation as #5-5. | 6-21 | Low likelihood, |
| | **(18) Install a new lead seal. Attach the regulator to the cylinder gas valve, and secure it in place by tightening the yoke assembly.** | | | | | |
| Part of | Incorrect lead seal installation | Serviceman does not install the lead seal or uses the old seal. [+ HF: experienced serviceman knows importance of new seal.] | Same as #6-21, | Same as #6-21. | 6-22 | Same as #6-21. |
| Less | Not tight enough | Serviceman does not tighten the yoke assembly enough, [+ HF: serviceman experienced with cylinder yoke attachment. 1 | Same as #6-21, | Same as #6-21. | 6-23 | Same as #6-21. |
| More | Too tight | Serviceman over-tightens the yoke assembly. [ + HF: serviceman experienced with cylinder yoke attachment. ] | Breaks the yoke; replacement of cylinder is delayed. | | 6-24 | Low likelihood. |

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|---|---|---|---|
| LANT/OPERATION: | Water Treatment Facility / Procedures | REVIEW DATE | 5/21/93 |
| INE/VESSEL/NODE: | Node 6 | DRAWING NO.: | Procedures for the Change-out of Chlorine Cylinders (see Appendix A) |
| ESIGN INTENTION | Install Replacement Chlorine Cylinder (west cylinder) | REVIEW TEAM: | F. Leverenz, J. Rude, S. Camp, D. Ortiz, J. Angyus, R. Hansen |

Guide Words without meaningful deviations have been omitted from this table.

| GUIDE WORD | DEVIATION | CAUSE | CONSEQUENCES | PROTECTION | SCE-NARIO | ACTIONS / COMMENTS |
|---|---|---|---|---|---|---|
| )ther han | Wrong angle valve | Serviceman installs regulator on the liquid valve. [+ HF: serviceman experienced with attachment and must install upside down.] | Same as #6-16. | 1 ) Same as #6-16.<br>2) Tour surveillance notices regulator upside down. | 6-25 | Low likelihood. |
| | (19) Check for leaks. Slowly open the chlorine cylinder gas supply valve. | | | | | |
| 'art of | Not check for leaks | Serviceman does not check for leaks. | Loss of protection in previous scenarios. | | 6-26 | No direct consequence. |
| Vlore | Opens too fast | Serviceman opens valve too fast. | Releases more chlorine than necessary for leak detection.<br><br>No health effects expected. | None.<br><br>Personal protective equipment for serviceman and operator. | 6-27 | Low likelihood. |
| | (20) Adjust the cylinder weight scale to indicate 2,000 pounds of product available in the cylinder. | | | | | |
| | No meaningful deviations | | | | | |
| | (21) Open system supply valves G-1 and G-5. | | | | | |
| Vo or 'art of | Skip step or part of the step | Plant operator does not open the valves. | Replacement chlorine not available; loss of chlorination. Same as #l-1. | 1 ) High vacuum alarm.<br>2) Residual $C1_2$ surveillance checks (see also #1-1, Protection 3). | 6-28 | Sufficient protection. |
| -ess | Not opened completely | Plant operator does not open one or both of the valves completely. | No consequence. | | 6-29 | |
| Other than | Wrong valve selected | Plant operator opens the G3 valve instead of the G 5 valve. [—HF: several valves in one location.] | Draws $Cl_2$ from both cylinders at the same time. Potential for loss of chlorination (see #1 -1). | 1 ) Surveillance checks weight of cylinders.<br>2) Surveillance checks rate indicators on regulators. | 6-30 | Minor consequences. |

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| LANT/OPERATION: | Water Treatment Facility / Procedures | REVIEW DATE: | 5/21/93 |
| INE/VESSEL/NODE: | Node 6 | DRAWING NO.: | Procedures for the Change-out of Chlorine Cylinders (see Appendix A) |
| ESIGN INTENTION: | Install Replacement Chlorine Cylinder (west cylinder) | REVIEW TEAM: | F, Leverenz, J. Rude, S. Camp, D. Ortiz, J. Angyus, R. Hansen |

Guide Words without meaningful deviations have been omitted from this table,

| GUIDE WORD | DEVIATION | CAUSE | CONSEQUENCES | PROTECTION | SCE-NARIO | ACTIONS/COMMENTS |
|---|---|---|---|---|---|---|
| | (22) Record in the log book the chlorine cylinder identification number and the scale weight. | | | | | |
| | No meaningful deviations | | | | | |
| | (23) Report any deficiencies to the supervisor for initiation of necessary corrective action. | | | | | |
| No | Skip step | Notification not made. | Delay in completing action. | | 6-31 | Minor consequences, |
| | (24) Notify the Hanford Fira Department and the 364 Powerhouse that the chlorine cylinder change-out activities are complete. | | | | | |
| No | Skip step | Notification not made. | No consequence. | | 6-32 | Minor consequence. |
| | (25) Close the roll-up door, and axit through the walk-through door. | | | | | |
| | No meaningful deviations | | | | | |

# APPENDIX C

# ESTIMATING THE EFFECTS OF CHLORINE RELEASES

# APPENDIX C: ESTIMATING THE EFFECTS OF CHLORINE RELEASES

Information contained in this appendix was excerpted, with permission, from *Estimating the Area Affected by a Chlorine Release (The* Chlorine Institute, 1991). The computer dispersion model used by The Chlorine Institute to generate release scenarios was based on generic industrial accidents and atmospheric conditions. The results depend on the atmospheric conditions and wind speeds assumed for the releases as well as on the terrain. They serve as an aid to estimating the range of potential consequences of chlorine releases. The HAZOP study team used this reference for the release and dispersion of chlorine to understand the potential consequences and impacts of releases.

## C.1 Characteristics of Chlorine Releases

Unintended chlorine releases have occurred as a result of industrial accidents involving equipment such as tanks, pipelines, relief valves, and vents.

Chlorine releases can be modeled as either instantaneous puff releases or continuous releases. During an instantaneous release, such as a cylinder rupture, large amounts of chlorine are released in a relatively short period of time. In a continuous release, such as the failure of a gasket, the chlorine release rate is maintained over a period of time until it is controlled or until the cylinder is depleted.

Initially, during a cylinder release, either gaseous or liquid chlorine, or both, may be released. As a result of the release, the pressure and temperature in the cylinder decreases, slowing the release rate. Upon release, pressurized liquid chlorine cools to its boiling point (-29°F) and boils off. Mixing with the atmosphere is delayed because the liquid must first evaporate. Chlorine vapors, however, mix immediately. If released under pressure, liquid chlorine can flash to a vapor, resulting in a two-phased jet release.

During the intermediate phases of a chlorine release, the chlorine is most influenced by atmospheric conditions. It continues to mix with the air and with moisture in the air. Depending on atmospheric conditions, aerosols may form. Eventually, a dense gas plume forms. This heavier-than-air plume remains at ground level as it moves downwind until, through dilution, its density equals the density of air.

Because of the atmospheric variability, stability classes are used to predict the dispersion of the plume. In the early morning, the atmosphere is stable. Daytime solar heating creates air movement and an unstable atmosphere. Atmospheric stability classes range from "very unstable" Class A to "very stable" Class G. Dispersion is also affected by the wind, the mixing height, and the terrain.

## C.2 Chlorine Release Scenarios

The consequences of the accident scenarios identified during the HAZOP study can be categorized as:

- Chlorine cylinder releases
- Process line breaks and releases
- Process equipment leaks.

The potential accident scenarios are identified in the HAZOP Study Worksheets (Appendix B).

To estimate the potential consequences and impacts of these accidents, release scenarios were selected from *Estimating the Area Affected by a Chlorine Release. The* scenarios are based on typical industrial accidents with conservative modeling assumptions. Five accident scenarios were selected for consideration:

1. A 1-ton cylinder is struck and its liquid valve is sheared off, resulting in the release of liquid chlorine.

2. Half-inch tubing is sheared off and chlorine gas is released (modeled with infinite supply).

3. A l-inch pipe is sheared off and chlorine gas is released (modeled with infinite supply) .

4. Half-inch tubing is sheared off and liquid chlorine is released (modeled with infinite supply).

5. **A** l-inch pipe is sheared off and liquid chlorine is released (modeled with infinite supply).

The assumptions for these five release scenarios are

- Three-foot release height

- Ambient air temperature of 68°F

- Ambient relative humidity of 50 percent

- Liquid or gaseous chlorine at 68°F

- Changes in ambient temperature or relative humidity assumptions have little effect on dispersion. Changes in assumptions about temperature and pressure of chlorine prior to release can significantly affect dispersion.

- Five-mile-per-hour wind speed. Because ambient concentration is inversely proportional to wind sped, concentrations can reconverted to other wind conditions by dividing 5 miles per hour by the actual wind speed and multiplying the result by the concentration.

- Average wind fluctuation of approximate] y 5°. If wind shifts are greater, the area impacted by the plume is greater.

- Stability Classes:

  -- Stability Class B: Strong and moderate solar radiation with low wind speed. Occurs during the day, generally in the mornings, with clear skies and wind speed less than 10 miles per hour.

  -- Stability Class F: Occurs at night, with wind sped less than 6 miles per hour, and with less than 40 percent cloud cover.

  -- Stability Class D: Used when classes B and F are not applicable.

## C.3 Predicted Chlorine Consequences

Figures C-1 through C-5 show graphically the areas potentially affected by chlorine releases for five generic accident scenarios*. Downstream distances are depicted at which chlorine concentrations exceed 25 parts per million (ppm) and 10 ppm.

The dispersion distances and downwind concentrations of chlorine resulting from the scenario modelling are summarized in Table C-1. The 25-ppm chlorine concentration is the immediately-dangerous-to-life-or-health (IDLH) level for chlorine, and 10 ppm is 40 percent of the IDLH. Ten ppm was chosen as a reference point for emergency planning because of the uncertainty in dispersion modeling.

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* The graphs in Figures C-1 through C-5 are truncated on the right-hand side of the x-axis. In fact, these curves extend to meet the x-axis. Limitations in display prevented the full extension from being shown.

## C.4 Potential Impacts of Chlorine Releases at the Hanford 300-Area Water Treatment Facility

If a large chlorine release occurs from the Hanford 300-Area Water Treatment Facility, wind from the northwest, west, and southwest would disperse it across the Columbia River to the residences on the far side, more than 3/4 of a mile away. In addition, boaters on the river and any workers occupying the pump house would also likely be exposed. The pump house, however, is normally unoccupied.

Wind from the north would carry a large chlorine plume to the 337 Office Building, resulting in the potential exposure of its more than 300 occupants. Small releases of chlorine would probably result in minor irritations to workers in the area.

Table C-1. Summary of Dispersion Distances and Downwind Concentrations for Chlorine Release Scenarios

| Scenario Description | Stability Class B Distance in feet and miles | | Stability Class D Distance in feet and miles | | Stability Class F Distance in feet and miles | |
|---|---|---|---|---|---|---|
| | 25 ppm | 10 ppm | 25 ppm | 10 ppm | 25 ppm | 10 ppm |
| 1) A l-ton cylinder is struck and its liquid valve is shared off. Liquid chlorine is released from a 3/8-inch hole. | 3,600<br>0.7 | **5,400**<br>1.0 | **5,400**<br>1.0 | 9,600<br>1.8 | 10,800<br>2.0 | 18,000<br>3.4 |
| 2) Half-inch, type-K copper tubing is sheared off. Chlorine gas is released (modeled with infinite supply). | 800<br>0.2 | 1,200<br>0.2 | 1,200<br>0.2 | 2,100<br>0.4 | 1,800<br>0.3 | 3,300<br>0.6 |
| 3) A l-inch schedule-80 pipe is sheared off. Chlorine gas is released (modeled with infinite supply). | 1,600<br>0.3 | 2,800<br>0.5 | 2,600<br>0.5 | **4,400**<br>0.8 | **4,200**<br>0.8 | **7,400**<br>1.4 |
| 4) Half-inch, type-K copper tubing is sheared off. Liquid chlorine is released (modeled with infinite supply). | 2,000<br>0.4 | 3,750<br>0.7 | 3,000<br>0.6 | 5,500<br>1.0 | 5,250<br>1.0 | 9,250<br>1.8 |
| 5) A l-inch schedule-80 pipe is sheared off. Liquid chlorine is released (modeled with infinite supply). | 4,000<br>0.8 | 7,000<br>1.3 | 7,000<br>1.3 | 7,000<br>2.0 | 11,000<br>2.0 | 18,500<br>3.5 |

**Scenario Description:**

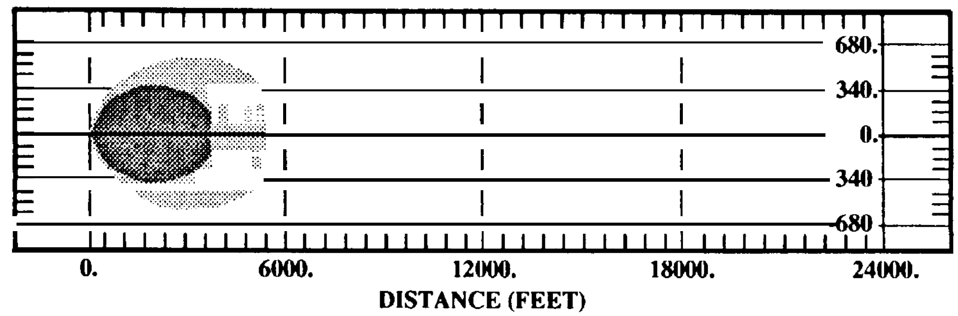
a. A 1-ton cylinder is struck and its liquid valve is sheared off. Liquid chlorine is released from a 3/8-inch hole.

b. The container is full = 2,000 pounds $Cl_2$.

c. The valve body has a 3/8-inch hole.

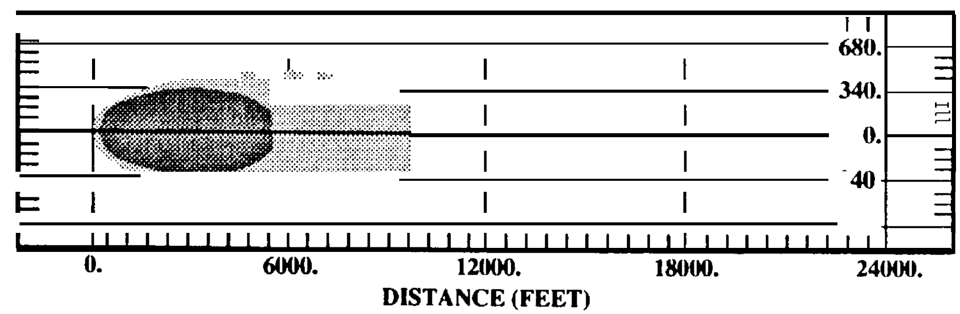
d. Release height is 3 feet. The container is on a concrete slab.

**Stability Class B**
Morning - Clear, Low Winds
Y-Axis Distance in Feet



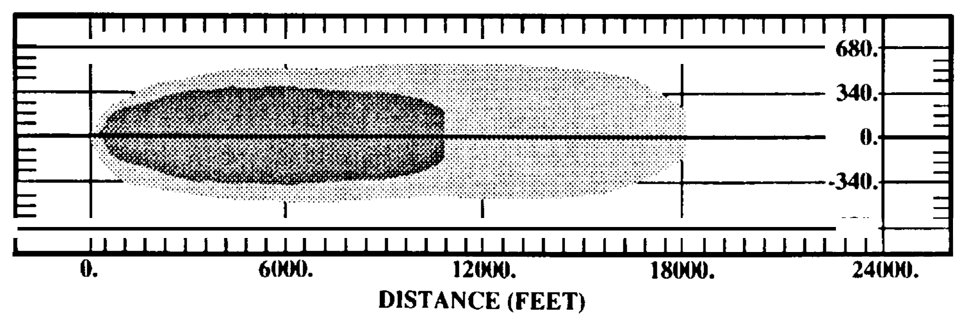

**Dark shading** Concentration Exceeds 25 ppm
**Light shading** Concentration Exceeds 10 ppm

**Stability Class D**
All other Conditions
Y-Axis Distance in Feet




**Dark shading** Concentration Exceeds 25 ppm
**Light shading** Concentration Exceeds 10 ppm

**Stability Class F**
Nighttime - Mostly Clear Skies, Low Winds
Y-Axis Distance in Feet




**Dark shading** Concentration Exceeds 25 ppm
**Light shading** Concentration Exceeds 10 ppm

**Figure** C-1. One-Ton Liquid Chlorine Release from Sheared-off Valve

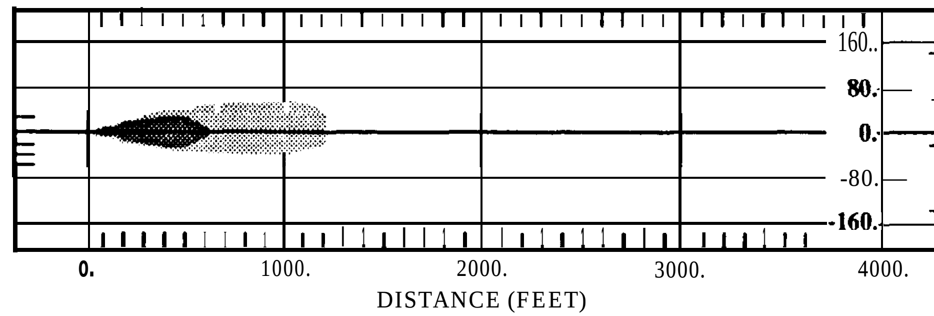
**scenario Description:**

**a.** Half-inch, type-K copper tubing is sheared off. Chlorine gas is released (modeled with infinite supply).

b. Release height is 3 feet.

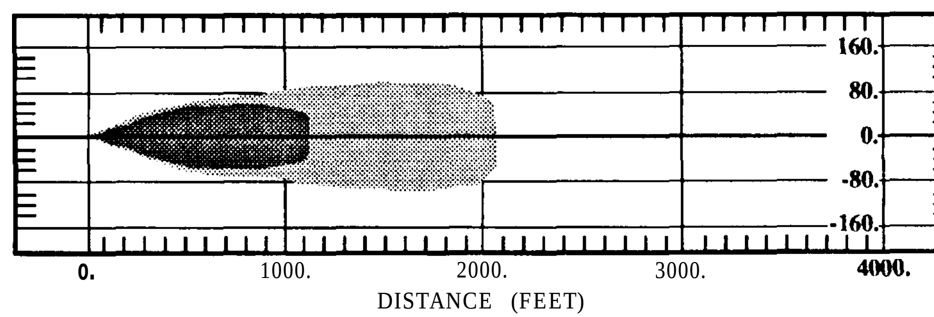
**Stability Class B**
Morning - Clear, Low Winds
Y-Axis Distance in Feet

**Dark shading** **Concentration Exceeds 25 ppm**
**Light shading** **Concentration Exceeds 10 ppm**




**Stability Class D**
All other Conditions
Y-Axis Distance in Feet

**Dark shading** **Concentration Exceeds 25 ppm**
**Light shading** **Concentration Exceeds 10 ppm**




**Stability Class F**
Nighttime - Mostly Clear Skies, Low Winds
Y-Axis Distance in Feet

**Dark shading** **Concentration Exceeds 25 ppm**
**Light shading** **Concentration Exceeds 10 ppm**

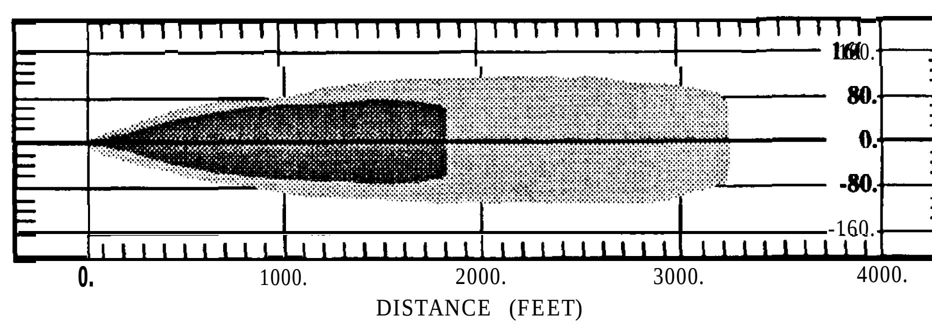



**Figure C-2. Chlorine Gas Release from Sheared-off 1/2-inch Tubing**

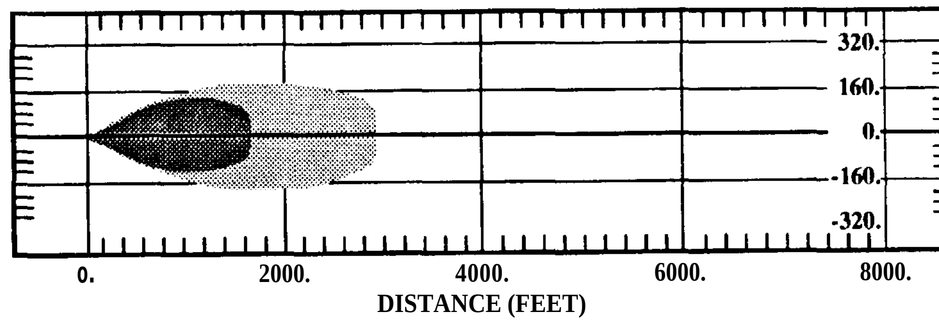
**Scenario Description:**

**a.** A l-inch, schedule-80 pipe is sheared off. Chlorine gas is released (modeled with **infinite** supply).

b. Release height is 3 feet.

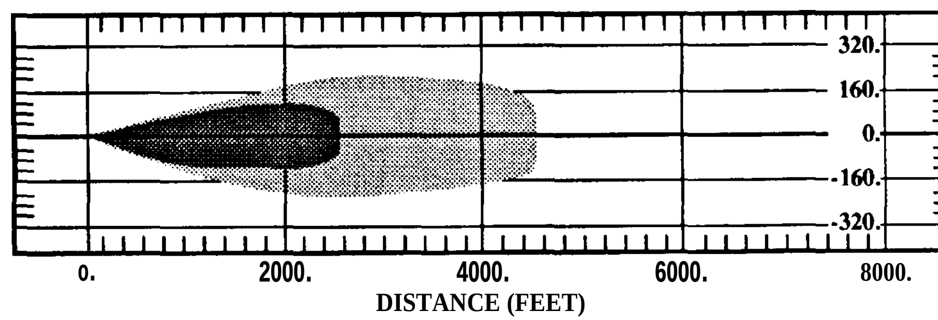
**Stability Class B**
Morning - Clear, Low Winds
Y-Axis Distance in Feet

**Dark shading** **Concentration Exceeds 25 ppm**
**Light shading** **Concentration Exceeds 10 ppm**




**Stability Class D**
**All** other Conditions
Y-Axis Distance in Feet

**Dark shading** **Concentration Exceeds 25 ppm**
**Light shading** **Concentration Exceeds 10 ppm**




**Stability Class F**
Nighttime - Mostly Clear Skies, **Low** Winds
Y-Axis Distance in Feet

**Dark shading** **Concentration Exceeds 25 ppm**
**Light shading** **Concentration Exceeds 10 ppm**

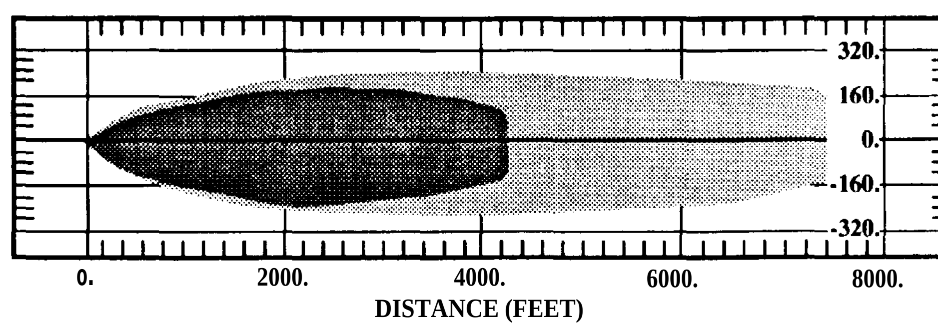


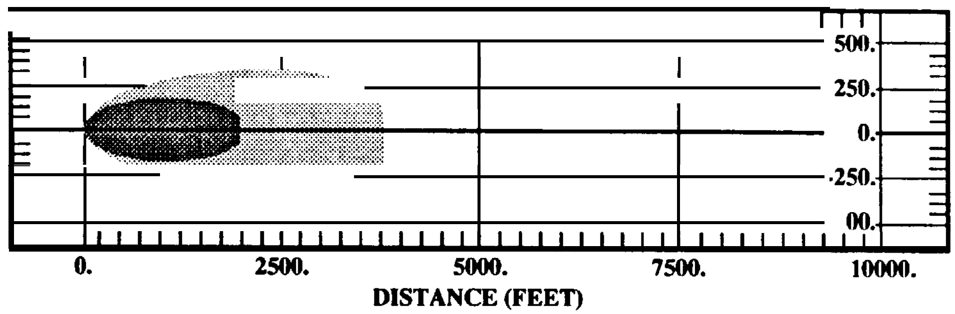

**Figure C-3. Chlorine Gas Release from 1-inch Pipe Break**

**Scenario Description:**

a. Half-inch, type-K copper tubing is sheared off. Liquid chlorine is released (modeled with infinite supply).

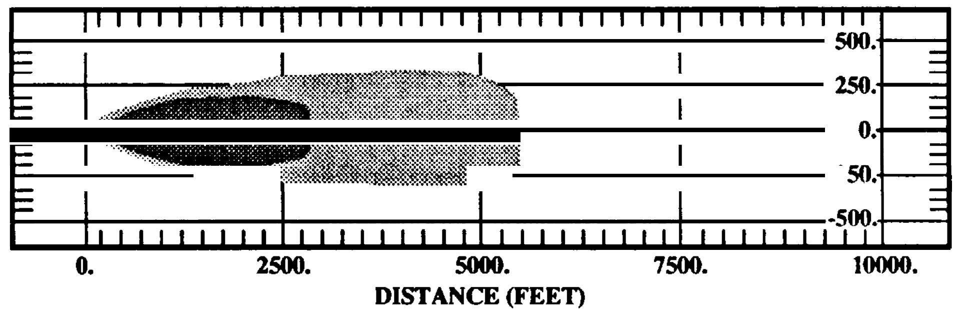
b. Release height is 3 feet.

**Stability Class B**
Morning - Clear, Low Winds
Y-Axis Distance in Feet



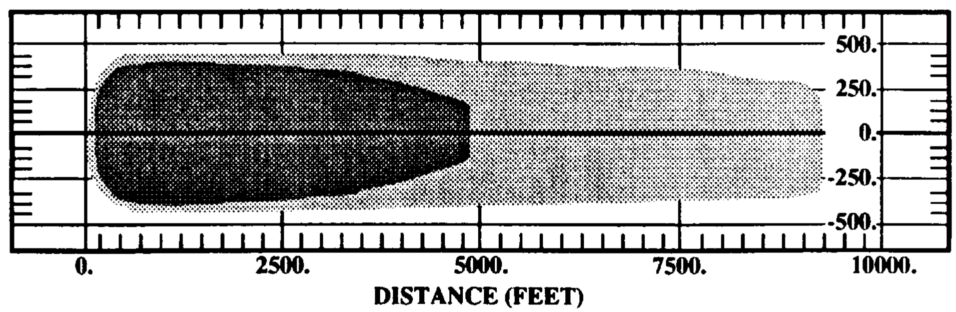

**Dark shading** Concentration Exceeds 25 ppm
**Light shading** Concentration Exceeds 10 ppm

**Stability Class D**
All other Conditions
Y-Axis Distance in Feet




**Dark shading** Concentration Exceeds 25 ppm
**Light shading** Concentration Exceeds 10 ppm

**Stability Class F**
Nighttime - Mostly Clear Skies, Low Winds
Y-Axis Distance in Feet




**Dark shading** Concentration Exceeds 25 ppm
**Light shading** Concentration Exceeds 10 ppm

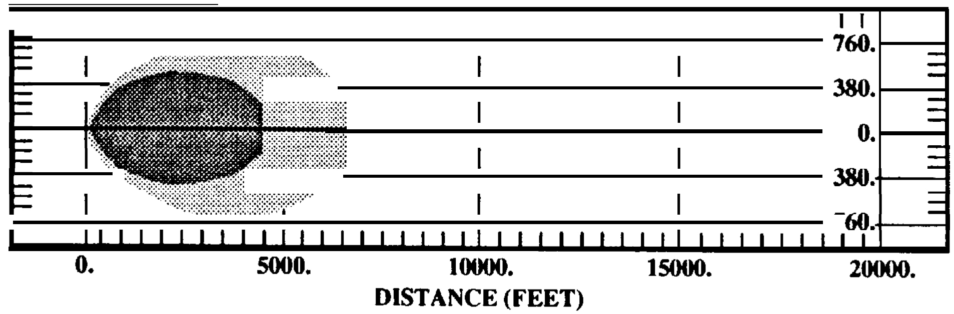
**Figure** C-4. Liquid Chlorine Release from Sheared-off l/2-inch Tubing

**Scenario Description:**

a. A 1-inch, schedule-80 pipe is sheared off. Liquid chlorine is released (modeled with infinite supply).

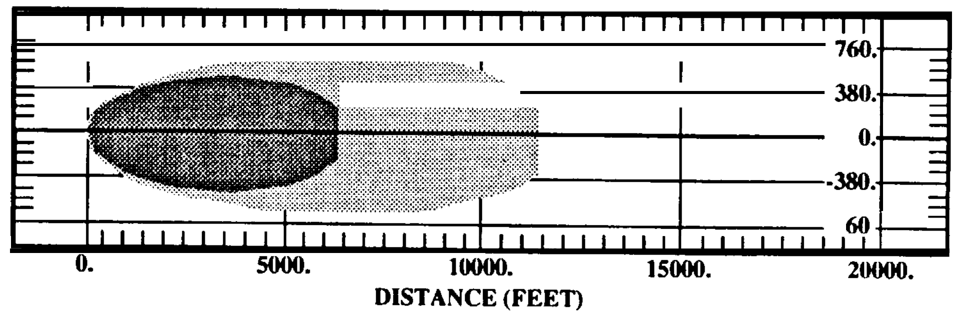
b. Release height is 3 feet.

**Stability Class B**
Morning - Clear, Low Winds
Y-Axis Distance in Feet



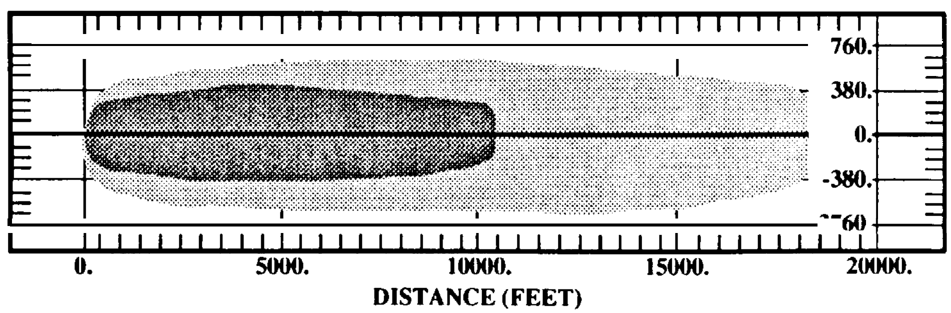

Dark shading — Concentration Exceeds 25 ppm
Light shading — Concentration Exceeds 10 ppm

**Stability Class D**
All other Conditions
Y-Axis Distance in Feet




Dark shading — Concentration Exceeds 25 ppm
Light shading — Concentration Exceeds 10 ppm

**Stability Class F**
Nighttime - Mostly Clear Skies, Low Winds
Y-Axis Distance in Feet




Dark shading — Concentration Exceeds 25 ppm
Light shading — Concentration Exceeds 10 ppm

Figure C-S. Liquid Chlorine Release from I-inch Pipe Break

# APPENDIX D

# MATERIAL SAFETY DATA SHEET FOR CHLORINE

# APPENDIX D: MATERIAL SAFETY DATA SHEET FOR CHLORINE*

| SECTION 1: CHEMICAL PRODUCTS& COMPANY IDENTIFICATION | |
|---|---|
| Occupational Health Services, Inc.<br>11 West 42nd Street, 12th Floor<br>New **York, New** York 10036<br>**1-800-445-MSDS** (1-800+5-6737) or<br>1-212-789-3535 | For Emergency Source **Information Contact:**<br>1-615-366-2000 |
| **Substance: Chlorine** | CAS **Number:** 7782-50-5<br>RTECS **Number:** FO21OOOOO |
| **Trade Names/Synonyms:** **Chlorine Molecular;** Chlorine Mol.; **Diatomic** Chlorine; Dichloride; Molecular Chlorine; STCC 4904120; UN 1017 **CL2;** 0HS04600 | |
| **Chemical** Family: Halogen | Inorganic Gss |
| SECTION 2: **COMPOSITION/INFORMATION** OF INGREDIENTS | |
| **Component: Chlorine** | **CAS Number: 7782-50-5** |
| **Percentage:** 100.0 | Other **Contaminants: None** |
| **SECTION 3: HAZARDS IDENTIFICATION** | |
| CERCLA Ratings **(Scale** O-3): **Health=** 3 **Fire=0** Reactivity=O Persistence=O<br>**NFPA** Ratings **(Scale 0-4):** **Health=** 3 **Fire=0** Reactivity=O | |
| Emergency Overview: Chlorine is a **greenish-yellow gas with a strong odor. Harmful if inhaled. Causes respiratory tract, skin,** and eye burns. Container may rupture in heat or fire. May ignite combustibles. Do not breathe gas. Do not get in eyes, on skin, or on clothing. Keep away from heat and flame. Store away from combustible materials. Do not puncture container. Keep **containe** tightly closed. Wash thoroughly **after** handling. Use ordy with adequate ventilation. | |
| Potential **Health** Effects:<br><br>Short Term Exposure: May cause sores, frostbite, runny nose, sneezing, paleness, hoarseness, tearing, blurred vision, drooling, bloody spit, stomach pain, coughing, difficulty breathing, lung damage, bluish skin color, **suffocation, weakness, headache, anxiety, restlessness, dizziness, irregular heartbeat, heart failure, collapse, and shock. May also cause death.**<br><br>**Long Term Exposure: May cause skin sores, acne, tooth decay, and lung effects.** | |
| **carcinogen status:** **OSHA:** N<br>**NTP:** N<br>**IARC:** N | |

* **Adapted by** permission of Occupational Health **Services,** Inc.

## SECTION 4: FIRST AID MEASURES

**Inhalation:** First Aid — Remove from exposure area to fresh air immediately. If breathing has stopped, give artificial respiration. Maintain airway and blood pressure and administer oxygen if available. Keep affected person warm and at rest. Treat symptomatically and supportively. Administration of oxygen should be performed by qualified personnel. Get medical attention immediate y.

**Skin Contact:** First Aid — Remove contaminated clothing and shoes immediately. Wash affected area with soap or mild detergent and large amounts of water until no evidence of chemical remains (at least 15-20 minutes). In case of chemical bums, cover area with sterile, dry dressing. Bandage securely, but not too tightly. Get medical attention immediately.

**Eye Contact:** Firat Aid – Wash eyes immediately with large amounts of water, occasionally lifting upper and lower lids, until no evidence of chemical remains (at least 15-20 minutes). Continue irrigating with normal saline until the pH has returned to normal (30-60 minutes). Cover with sterile bandages. Get medical attention immediately.

**Ingestion:** First Aid — Do not use gastric lavage or emesis. Dilute the acid immediately by drinking large quantities of water or milk. If vomiting persists, administer fluids repeatedly. Ingested acid must be diluted approximately 100 fold to render it harmless to tissuea. Maintain airway and treat shock (Dreisbach, handbook of poisoning, 12th cd.). Get medical attention immediately. If vomiting occurs, keep head below hips to help prevent aspiration.

**Note to physician:**

Antidote: No specific antidote. Treat symptomatically and supportively.

## SECTION 5: FIRE FIGHTING MEASURES

**Fire and Explosion Hazard:** Negligible fire hazard when exposed to heat or flame.

**Oxidizer:** Oxidizers decompose, especially where heated, to yield oxygen or other gases which will increase the burning rate of combustible matter. Contact with easily oxidizable, organic, or other combustible materials may result in ignition, violent combustion or explosion.

**Extinguishing Media:** Water only, no dry chemical, carbon dioxide or halon (1990 Emergency Response Guidebook, DOT P 5800.5). For larger fires, use water spray or fog (1990 Emergency Response Guidebook, DOT P 5800.5).

**Firefighting:** Move container from fire area if you can do it without risk. Apply cooling water to sides of containers that are exposed to flames until well after fire is out. Stay away from enda of tanks. For massive fire in cargo area, use unmanned hose holder or monitor nozzles; if this is impossible, withdraw from area and let fire bum. For small fires, contain and let bum; if fire must be fought, water spiny or fog is recommended (1990 Emergency Response Guidebook, DOT P 5800.5, guide page 20).

Extinguish using agents suitable for type of fire. Cool containers with flooding amounts of water, apply from as far a distance as possible. Avoid breathing poisonous vapors, keep upwind. Evacuate to a radius of 2,500 feet if material is leaking.

**Hazardous Combustion products:** Thermal decomposition products may include toxic and corrosive fumes of chlorine,

## SECTION 6: ACCIDENTAL RELEASE MEASURES

Occupational Spill: Stop leak if you can do it without risk. Keep combustibles away from spilled material. Keep unnecessary people away; isolate area and deny entry until gas has dispersed. Ventilate closed spaces before entering.

Reportable Quantity (RQ): 10 pounds

The Superfund Amendments and Reauthorization Act (SARA) Section 304 requires that a release equal to or greater than the reportable quantity for this substance be immediately reported to the local emergency planning committee and the state emergency response commission (40 CFR 355.40). If the release of this substance is reportable under CERCLA Section 103, the National Response Center must be notified immediately at (800) 424-8802 or (202) 426-2675 in the metropolitan Washington, DC, area (40 CFR 302.6).

Soil Spill: Dig a pit, pond, lagoon or holding area to contain liquid or solid material. Dike surface flow using soil, sandbags, foamed polyurethane or foamed concrete. Absorb bulk liquid with fly ash or cement powder. Add caustic soda.

Air Spill: Apply water spray to knock down and reduce vapors. Knockdown water is corrosive and toxic and should be diked for containment and later disposal.

Water Spill: Neutralize with caustic soda.

If Dissolved, at a concentration of 10 ppm or greater, apply activated carbon at ten times the amount that has been spilled.

Use mechanical dredges or lifts to extract immobilized masses of pollution and precipitates.

## SECI'1ON 7: HANDLING AND STORAGE

Storage: Observe all federal, state and local regulations when storing or disposing of this substance. For assistance, contact the district director of the environmental protection agency.

Protect against physical damage. Separate from combustible, organic or easily oxidizable materials and especially isolate from acetylene, ammonia, hydrogen, hydrocarbons, ether, turpentine, and finely divided metals. Store outdoors or in a well-ventilated, detached or segregated areas of noncombustible instruction (NFPA 49, Hazardous chemicals Data, 1975).

Store away from incompatible substances.

Consult NFPA Publication 43C, Storage of Gaseous Oxidizing Materials, for storage requirements.

**Threshold Planning Quantity (TPQ): The** Superfund Amendments and Reauthorization Act (SARA) Section 302 requires that each facility where any extremely hazardous substance is present in a quantity equal to or greater than the TPQ established for that substance notify the state emergency response commission for the state in which it is located. Section 303 of SARA requires these facilities to participate in local emergency response planning (40 CFR 355.30).

## SECTION 7: HANDLING AND STORAGE (continued)

**Threshold Quantity (TQ)**: 1,500 pounds

The **Occupational** Safety and Health Administration **(OSHA)** process safety management **(PSM)** standard requires that facilities using a process that involves a chemical at or above its specified threshold quantity comply with the provisions of 29 CFR 1910.119, process Safety Management of Highly Hazardous Chemicals.

## SECTION 8: EXPOSURE CONTROLS/PERSONAL PROTECTION

**Exposure Limits:**

**Chlorine**:

0.5 ppm (1.5 mg/m$^3$) OSHA TWA; 1 ppm (3 mg/m$^3$ ) OSHA STEL
0.5 ppm (1.5 mg/m$^3$) ACGIH WA: 1 ppm (3 mg/m$^3$) ACGIH STEL
0.5 ppm (1.5 mg/m$^3$) NIOSH recommended TWA;
1 ppm (3 mg/m$^3$) NIOSH recommended STEL
0.5 ppm (1.5 mg/m$^3$)DFG MAK TWA;
1 ppm (3 mg/m$^3$) DFG MAK 5 minute peak, Momentary Value, 8 times/shift

**Measurement Method:** Bubbler; Ion-Specific electrode; (OSHA # 1D101).

100 pounds SARA Section 302 Threshold Planning Quantity
10 pounds SARA section 304 Reportable Quantity
10 pounds CERCLA Section 103 Reportable Quantity
1,500 pounds OSHA Process Safety Management Threshold Quantity
Subject to SARA Section 313 Annual Toxic Chemical release reporting.

**NOTE:** OSHA limits adopted January 19, 1989 are subject to the decision of the 11th Circuit Court of Appeals (AFL-CIO V. OSHA) as of July 7, 1992.

**Ventilation:** Provide local exhaust or process enclosure ventilation to meet published exposure limits.

**Eye Protection:** Employee must wear splash-proof or dust-resistant safety goggles and a faceshield to prevent contact with this substance.

**Emergency Wash Facilities: Where there is any** possibility that an employee's eyes and/or skin may be exposed to this substance, the employer should provide an eye wash fountain and quick drench shower within the immediate work area for emergency use.

Clothing: Employee must wear appropriate protective (impervious) clothing and equipment to prevent any possibility of skin contact with this substance.

**Gloves**: Employee must wear appropriate protective gloves to prevent contact with this substance.

**Respirator: The following** respirators and maximum use concentrations are recommendations by the U.S. Department of Health and Human Services, N1OSH Pocket Guide to Chemical Hazards; N1OSH criteria documents or by the U.S. Department of Labor, 29 CFR 1910 Subpart Z.

The specific respirator selected must be based on contamination levels found in the work place, must not exceed the working limits of the respirator and be jointly approved by the National Institute for Occupational Safety and Health and The Mine Safety and Health Administration (N1OSH-MSHA).

## SECTION 8: EXPOSURE CONTROLWPERSONAL PROTECTION (continued)

**Chlorine**:

**5 ppm – Arty** chemical cartridge respirator with cartridge(s) providing protection against chlorine. Any supplied-air **respirator.** Any self-contained breathing apparatus.

**12.5 ppm —** .4ny supplied-air respirator operated in a continuous-flow mode. Any powered, air-purifying **respirator** with cartridge(s) providing protection against chlorine.

**25 ppm — Any** self-contained breathing apparatus with a **full facepiece.** Any supplied-air respirator with a **full facepiece.** Any **air-purifying, full-facepiece** respirator (gas mask) with a chin-style, front- or back-mounted canister providing protection any powered, **air-purifying respirator** with a tight-fitting **facepiece.** Any cartridge(s) providing **protection** against chlorine. Any chemical cartridge **respirator** with a **full facepiece and cartridge(s)** providing protection against chlorine.

**30 ppm – Any** supplied-air respirator that has a **full facepiece** and **is** operated in a **pressure-demand** or other Positiv-pressure mode.

**Escape —** any air-purifying, **full-facepiece** respirator (gas mask) with a chin-style, front- or back-mounted canister providing protection against chlorine. Any appropriate **escape-type,** self-contained breathing apparatus.

**For Firefighting and Other Immediately Dangerous to Life or Health** Conditions:

Any self-contained breathing apparatus that has a **full facepiece** and is **operated** in a **pressure-demand** or other **positive-pressure** mode.

Any supplied-air **respirator** that has a **full facepiece** and is operated in an **pressure-demand** or other **positive-pressure** mode in combination with an auxiliary **self-contained** breathing apparatus **operated** in **pressure-demand** or other **positive-pressure** mode.

## SECTION 9: PHYSICAL AND CHEMICAL PROPERTIES

| | |
|---|---|
| **Description:** Pale greenish-yellow gas with a characteristic, **suffocating** odor. | **Molecular Weight: 70.906** |
| **Molecular Formula:** $Cl_2$ | **Boiling Point**: **–3** 1°F **(—35°C)** |
| Melting **Point**: **—150°F** (–101”C) | **Vapor Pressure (mm Hg):** 5168 mm **Hg @** 21°C |
| **Vapor Density (Air = l):** 2.49 | **Specific** Gravity **(water = l):** 3.214 grams/liter **@ 0°C** |
| **Water Solubility: 1.46% @ 0°C** | **Odor Threshold:** 0.01 ppm |
| Solvent **Solubility**: Soluble in alkalies. | |

## SECTION 10: STABILITY AND REACTIVITY

**Reactivity: Stable under normal temperatures and pressures.**

**Conditions to Avoid: Avoid contact with combustible materials (wood, paper, oil, etc); contact may result in ignition or explosion. Material may be poisonous; avoid inhalation of vapors or contact with skin. Do not allow material to contaminate water sources.**

**Chlorine Incompatibilities:**

Acetylene Explosive reaction

**Alcohols**: Formation of explosive alkyl hypochlorites.

**Alkyl Isothiourea** Salts: Formation of explosive nitrogen trichloride.

**Ammonia**: Explodes when heated.

**Antimony**: Ignition reaction

**Arsenic**: Spontaneous ignition.

**N-Arylsulfinamides**: Possible violent reaction.

Benzene: Explosive reaction catalyzed by light

Boron: Ignites on contact.

Bromine **Pentafluoride**: Explosive reaction.

**Calcium Chlorite**: Forms explosive chlorine dioxide.

**Calcium Nitride**: Incandescent reaction.

Carbon (activated): Ignites on contact.

Carbon **disulfide**: Explosive reaction in the presence of iron catalyst.

**Cesium Nitride**: Attacked by chlorine.

**3-Chloropropyne**: Possible explosion.

**Chromyl Chloride** + Carbon: Possible explosion.

Combustible **Materials**: Contact with the liquid is likely to result-in an explosion. Contact with the gas may result in ignition or an explosion.

**Diborane**: Explodes on contact at ambient temperatures.

**Dichloromethylarsine**: Possible explosion.

**Diethyl Ether**: Explodea.

**Diethylzinc**: Ignition.

**Dimethylformamide**: Explosion hazard.

**Dimethyl Phosphoramidate**: May form explosive nitrogen trichloride.

**Dioxygen Difluoride**: Ignition or explosive reaction.

**Disilyl Oxide**: Explosive reaction.

4,4' — **Dithiodimorpholine**: May form explosive compound.

| SECTION 10: STABILITY AND Reactivity (continued) |
|---|
| **Ethylene:** Explosive reaction in the presence of light or catalysts. |
| **Ethylene I mine:** Formation of explosive **-chloroethylene imine.** |
| **Ethylphosphine:** Explosion on contact. |
| **Flammable** compounds: Contact with the liquid is **likely** to **result** in an explosion. Contact with the gas may result in ignition or an explosion. |
| Fluorine: Ignition followed by **explosion on sparking.** |
| **Hexachlorodisilane: Ignition above 200° C with** possible explosion. |
| **Hydrazine:** Ignition reaction. |
| **Hydrocarbons: Contact** with the liquid ia likely to result in an explosion. Contact with the gas may result in ignition or an explosion. Addition of a Lewis acid to **chlorine-hydrocarbon** mixtures will **result** in the release of large **volumes** of **hydrogen** chloride. |
| **Hydrogen:** Explosive mixtures. |
| **Hydrogen** Peroxide + Potassium **Hydroxide:** Luminescent reaction. |
| **Hydroxylamine:** Spontaneous ignition. |
| **Iodine:** Violent reaction. |
| **Iron Carbide:** Incandescent reaction. |
| **Lithium Silicide: Incandescent** reaction **when** heated. |
| **Metals and Alloys:** Ignition on contact; some metals may be corroded in the presence of moisture. |
| **Metal Acetylides:** Ignition Reaction. |
| Metal **Hydrides:** Ignition. |
| **Metal Oxides:** Vigorous reaction and possible ignition. |
| **Metal Phosphides:** Ignition. |
| **Nitrogen Compounds:** May form explosive nitrogen **trichloride.** |
| **Nitrogen Triiodide:** Explosive reaction on contact. |
| **Non-Metal Hydrides: Ignite** on **contact.** |
| Oxygen: Explosion on heating. |
| Oxygen **Difluoride:** Explodes on warming. |
| **Phenylmagnesium** Bromide: Possible explosion. |
| **Phosphorous:** Explosive reaction on **contact** with the liquid; ignition on contact with the gas. |
| **Phosphorous Compounds:** Ignition. |
| **Phosphorous Isocyanate: Vigorous** reaction. |
| **Polychlorobiphenyl: Exothermic** Reaction. |
| **(Poly) Oxomonosilane:** Ignition. |
| **Potassium Halides:** Ignition. |

**SECTION 10: STABILITY AND REACTIVITY** (continued)

**Sin:** Ignite-s on contact with gaseous chlorine at ambient temperatures.

Sines: Possible explosion on heating.

**Sodium Hydroxide:** Violent reaction.

**Stannous Fluoride: Reaction occurs with flaming.**

**Stibine: Explosive reaction if heated.**

**Sulfamic Acid**: May form explosive nitrogen **trichloride**.

**Sulfides**: Ignition.

**Tellurium:** Incandescent reaction.

**Tetramethyldiirsine: Spontaneous ignition.**

**Tetramethylsilane**: Possible explosion in presence of a catalyst.

**Tetraselenium Tetranitride**: Explosion on contact.

**Trialkylboranes**: Ignition reaction.

**Trimethyl Thionophosphate**: Possible explosion.

**Vanadium (Powder):** Explosion on contact with the liquid.

**Hazardous Decomposition: Thermal** decomposition products may include toxic and corrosive fumes of chlorine.

**Polymerization**: Hazardous polymerization has not been **reported** to occur under normal temperatures and **pressures.**

## SECTION 11: TOXICOLOGY INFORMATION

**Chlorine Toxicity Data: 2530 mg/m$^3$/30** minutes inhalation-human $LC_{LO}$; 500 **ppm/5** minutes **inhalation-**human $LC_{LO}$; 293 **ppm/1** hour inhalation-rat $LC_{50}$; 137 **ppm/1** hour inhalation-mouse $LC_{50}$; 660 **ppm/4** hours inhalation-rabbit $LC_{LO}$; 330 **ppm/7** hews inhalation-guinea pig $LC_{LO}$; **800 ppm/30** minutes inhalation-dog $LC_{LO}$; **660 ppm/4** hours inhalation-eat $LC_{LO}$; 500 **ppm/5** minutes inhalation-mammal $LC_{LO}$; **mutagenic data (RTECS)**; reproductive effects data **(RTECS)**.

Carcinogen Status: None.

**Local Effects**: Corrosive – Inhalation, skin, eye.

**Acute toxicity Level:** Toxic by inhalation.

**Target Effects**: Poisoning may affect the lungs.

**At Increased Risk from Exposure:** Persons with pm-existing **heart** disease or tuberculosis.

## SECTION 11: TOXICOLOGY INFORMATION (continued)

Health Effects:

**Inhalation of Chlorine:** Corrosive/Toxic

**30** ppm immediately dangerous to life or health.

**Acute Exposure –** Mucous membrane irritation may **occur** at 0.2 to 16 ppm and cough at 30 ppm. Inhalation of 500 ppm for 5 minutes has been **lethal** in humans and 1,000 ppm may be fatal after a few deep breaths. Occupational exposures have resulted in burning of the nose and mouth with **rhinorrhea,** respiratory distress **with** coughing, choking, wheezing, mica, **retching,** hemoptysis, **substernal** pain, **dyspnea,** and cyanosis. **Tracheobronchitis,** progressing to immediate or possibly delayed **pulmonary** edema and occasional **pneumonitis** have also been reported. Cough generally increases in frequency **and** severity **after** 2 to 3 days and became productive of thick **mucopurulent** sputum, which disappears by the end of 14 days. Lung damage is usually not permanent; respiratory distress usually subsides within 72 hours. At high concentrations, **chlorine** may act as an asphyxiant by causing cramps of the larynx muscles and **swelling** of the mucous membranes. other symptoms may include salivation, anxiety, sneezing, pallor or redness of the face, weakness, hoarseness, headache, dizziness, and general excitement and restlessness. Massive inhalation may also cause death by cardiac **arrest**.

**Chronic Exposure —** Persons repeatedly exposed to low concentrations may develop **chloracne,** olfactory deficiency and tolerance build-up. prolonged and **repeated** exposure to 0.8- 1.0 ppm may cause permanent, although moderate reduction in pulmonary function. Chronic exposure at 5 ppm may result in inflammation of the mucous membranes of the nose, disease of the bronchi, and increased susceptibility to respiratory infection including tuberculosis. Dental erosion may occur. Animals surviving sublethal exposures for 15 to 193 days alter gassing showed marked emphysema.

Skirt **Contact:**

**Chlorine:** Corrosive.

**Acute Exposure —** High vapor concentrations may irritate the skin and cause burning and pricking sensations, inflammation, and vesicle formation. Contact with liquid may **cause** bums, blistering, tissue **destruction,** and frostbite.

**Chronic Exposure – Effects** depend on the concentration and duration of exposure **Repeated** or prolonged **contact** may result in dermatitis or effects similar to acute exposure.

**Eye Contact:**

**Chlorine: Corrosive.**

**Acute Exposure –** Exposure to concentrations of chlorine gas as low as **3-6** ppm may **cause** redness, pain, **blurred** vision, and **lacrimation.** Direct **contact** with liquid may cause bums. Chlorine dissolved in water, and **placed** into the anterior chambers of rabbit eyes caused severe inflammation, **corneal** opacity, iris atrophy and injury to the lens.

**Chronic Exposure – Effects** depend on the **concentration** and duration of exposure. Repeated or prolonged exposure may cause conjunctivitis or **effects** as in acute exposure.

**Ingestion of Chlorine**:

**Acute Exposure –** Ingestion of a gas is very unlikely. Ingestion of the liquid may cause bums of the lips, mouth and mucous membranes of the **gastrointestinal** tract, possible ulceration or perforation, abdominal pain, **tachycardia,** prostration and **circulatory** collapse.

**Chronic Exposure – No data available.**

## SECTION 12: ECOLOGICAL INFORMATION

Environmental Impact Rating (O-3): No data available.

Acute Aquatic Toxicity: No data available.

Degradability: No data available.

Log Bioconcentration Factor (BCF): No data available.

Log Octanol/Water Partition Coefficient: No data available.

## SECTION 13: DISPOSAL INFORMATION

RCRA Hazardous Waste: No data available.

Waste Disposal: Disposal must be in accordance with standards applicable to generators of hazardous waste, 40 CFR 262, EPA Hazardous Waste number DOOl. A 100-pound (CERCLA Section 103) Reportable Quantity.

## SECTION 14 TRANSPORTATION INFORMATION

Department of Transportation Hazard Classification:
49 CFR 172.101, Nonflammable gas

Department of Transportation Labeling Requirements:
49 CFR 172.101 and Subpart E, Nonflammable gas and poison

Department of Transportation Packaging Requirements:
49 CFR 173.304; 49 CFR 173.314 and 49 CFR 173.315

Exceptions: None

Final ruk on hazardous materials regulations (HMR, 49 CFR Parts 171-180), Docket numbers HM-181, HM-181A, HM-181B, HM-181C, HM-181D and HM-204. Effective date October 1, 1991. However, compliance with the regulations is authorized on and after January 1, 1991. (55 FR 52402, 12/21/90).

Except for explosives, inhalation hazards, and infectious substances, the effective date for hazard communication requirements is extended to October 1, 1993. (56 FR 47158. 09/18/91).

U.S. Department of Transportation Shipping Name-ID Number:
49 CFR 172.101, Chlorine-UN 1017

U.S. Department of Transportation Hazard Class or Division:
49 CFR 172.101, 2.3- Poisonous Gas

U.S. Department of Transportation Labeling Requirements:
49 CFR 172.101 and Subpart E, Poison Gas

U.S. Department of Transportation Packaging Authorizations:

Exceptions: None

Non-Bulk Packaging: 49 CFR 173.304

Bulk Packaging: 49 CFR 173.314 and 49 CFR 173.315

## SECTION 14: TRANSPORTATION INFORMATION (continued)

U.S. Department of Transportation Packaging Authorizations: 49 CFR 172.101

Passenger Aircraft or Railcar: h-bidden

Cargo Aircraft Only: Forbidden

## SECTION 15: REGULATORY INFORMATION

TSCA Status: Y

Other Regulatory Information Available:

| | |
|---|---|
| CERCLA section 103 (40 CFR 302.4): | Yes 10 pounds RQ |
| SARA Section 302 (40 CFR 355.30): | Yea 100 pounds TPQ |
| SARA Section 304 (40 CFR 355.40): | Yea 10 pounds RQ |
| SARA Section 313 (40 CFR 372.65): | Yes |
| OSHA Process Safety (29 CFR 1910.119): | Yes 1,500 pounds TQ |
| California Proposition 65: | No |

SARA Hazard Categories, SARA Sections 311/312 (40 CFR 370.21)

| | |
|---|---|
| Acute Hazard: | Yea |
| Chronic Hazard: | No |
| Fire Hazard: | No |
| Reactivity Hazard: | No |
| Sudden Release Hazard: | Yes |

## SECTION 16: OTHER



Creation Date: 10/16/84 | Revision Date: 12/30/93

Licensed to: HEHF

# APPENDIX E:

# RÉSUMÉS OF HAZOP STUDY TEAM

## Karl D. Agee

**Westinghouse Hanford Company**

**Area of Responsibility**

**Industrial** Hygiene, Chemical Safety

**Experience**

15 years

- Performed surveys on a nationwide basis in manufacturing, petrochemical facilities, and offices to improve indoor air quality. Evaluated exposures to asbestos and fibrous glass fibers, wood dust, **respirable** silica, welding fumes, metals, and other airborne particulate. Monitored personal exposures to solvent vapors, sewer gases, plastic monomers and resins, carbon monoxide, and other gases and vapors.

- Conducted heat stress monitoring and surveying for **ionizing** and **non-ionizing** radiation hazards.

- Developed asbestos training programs for more than 1,000 workers. **Directed** bio-environmental engineering program for **Air National** Guard Base.

- Reviewed facilities engineering plans pertaining to industrial hygiene. Recommended corrections and/or designed ventilation systems at manufacturing facilities.

Education

B. S., Environmental Science, University of Michigan

**Other**

**Certified** Industrial Hygienist
Certified Hazardous Waste Worker

Samuel **L. Camp, Jr.** **Westinghouse Hanford Company**

**Area of Responsibility**

Hazard Analysis Process Operator, Process Safety and Risk Management

Experience

16 **years**

- Plant supervisor responsible for the operation of steam, water, process air, and sanitary sewer utilities of the Hanford 300-Area. Responsibilities include maintenance and operation of chlorination process equipment and the chlorine cylinder storage area. Assisted in development of the chlorine cylinder storage and handling facilities, chlorination process equipment, and operating procedures.

- Plant operator of steam, water, process air, and sanitary sewer utilities in the Hanford 300-Area. As plant operator, controlled chlorination system, including processing and chlorination of potable water, and sampling and testing of water in accordance with State of Washington code.

**Education**

U.S. Navy Basic Propulsion and Engineering School
U.S. Navy Boiler Technician “A” School

**Other**

**State** of Washington Group **II** Water Treatment Operator

## Rudv I. Hansen



**Area** of **Responsibility**

Hazard and Risk Analysis

**Experience**

**22 years**

- Experience in occupational safety, industrial hygiene, human factors, fire safety, and safety management.
- Consulted with numerous organizations on safety issues and processes. Assisted in program review and development and accident analysis. Performed safety process reviews and audits to determine general and chemical process hazards.
- Managed consultants and developed service programs to reduce accident frequency for the firms serviced. Managed training, industrial hygiene, and generaI safety programs for these consulting programs. other responsibilities included training, safety literature development, and performance management.
- Developed preliminary hazard analyses for new and existing U.S. Department of Energy research facilities.

**Education**

B. S., Physics, Oregon State University
M. S., Industrial Engineering, Oregon State University

**Other**

Certified Safety Professional

## **Sanjeeva M. Kanth** **U.S. Department of Energy**

**Area of Responsibility**

Process Safety Management

**Experience**

10 **years**

- U.S. Department of Energy, Occupational Safety and Health Manager. Responsible for development of technical guidance documents in occupational safety.

- DOE Program Manager. Responsible **for** development of tools **for** DOE-wide implementation of the Occupational Safety and Health Administration rule, 29 CFR 1910.119, "Process Safety Management of Highly Hazardous Chemicals. "

- **OSHA,** General Industry Compliance Assistance. As a safety engineer, responsible for development of the Special Emphasis Program, **PETROSEP,** which directed compliance personnel in conducting inspections at petrochemical facilities. Provided interpretation of OSHA standards and developed directives interpreting performance-based OSHA standards, Conducted chemical **plant** inspections assessing chemical process safety. Conducted workplace accident investigations involving chemical releases and explosions.

- West Virginia Department of Natural Resources, Division of Hazardous Waste Management. As a chemical engineer, reviewed Part B applications **for** Resource Conservation and Recovery Act facilities. Participated in the development of state hazardous waste management regulations.

**Education**

B. S., Chemical Engineering, **Osmania** University, **Hyberabad,** India
M. S., Chemical Engineering, **Ohio State University**

## Fred L. Leverenz, Jr. — Battelle-Columbus

**Area of Responsibility**

Process Hazard Anal ysis Leader, Process Safety and Risk Management

Experience

**20** years

- Hazard and operability **(HAZOP)** study leader **for** numerous facilities, including manufacturers of **sulfuric** acid, **oleum,** and liquid $S0_3$; a hydrocarbon recovery system; startup and operating procedures **for** three refineries; a state-of-the-art hazardous waste disposal **facility,** for which accident scenarios were assessed **for** frequency and consequences; a batch-process catalyst manufacturing plant survey and upgrade; and an advanced absorption heat transfer system.

- Led a preliminary hazard analysis for the **design** of a hazardous waste processing plant. PHA addressed the locations of hazards and their relative risks. Planned and led a risk audit of a chemical process plant that used large quantities of hydrogen sulfide. The audit covered process components, operation, and maintenance, and onsite transportation. Led a risk assessment of a chemical pilot **plant** where temperature **control** was critical. Used **fault trees** to model system **failures** that **could** cause loss of temperature control.

- Author of numerous publications on hazard evaluation and **HAZOP** study procedures.

- Presented numerous seminars and workshops on risk assessment. Currently leads the American Institute of Chemical Engineers Center **for** Chemical Process Safety continuing education course, "Use of Hazard arid Operability Studies in Process Risk Management. " This course has been presented to more than 1,200 engineers and 20 different companies.

**Education**

B. S., Electrical Engineering, University of **Cincinnati**
M. S., Engineering, University of Santa Clara

**Kenneth G. Murphy** U.S. **Department of Energy**

**Area of Responsibility**

Mechanical Engineering, Risk Assessment, Human Factors

**Experience**

30 years

- Us. Department of Energy, Risk Assessment Team Manager. As Safety Analysis Division Director, **performed** oversight of DOE safety analyses, development of safety and risk policies, and review of reactor and non-reactor probabilistic risk assessments.

- Nuclear Regulatory Commission, Region 1, Technical Assistant. Provided technical support to regional management concerning inspection activities and risk-based applications. Inspection team leader on major probabilistic risk assessment-based **inspections.** Program manager of **Calvert Cliff's** and **LaSalle PRAs.**

- Design and safety specialist in space electric and nuclear applications at **Hittman** Associates, Inc.

- U.S. Atomic Energy Commission. Program manager for space electric component development, reactor core and shielding design, and major nuclear project construction.

**Education**

B. S., Nuclear Engineering, New York State Maritime College
M. B.A., Engineering Management, George Washington University

**Other**

Certification, Oak Ridge School of Reactor Technology

**Area of Responsibility**

Chemical Engineering, Hazard and Risk Analysis

Experience

**20** years

- Group Leader, Risk and Safety Analysis.
- Project manager for the **Liquified** Gaseous Fuels Release Prevention and Control Project.
- Project manager, task manager, and technical contributor to numerous risk and safety analyses of energy-related systems, including nuclear reactors and **fuel** cycle facilities, nuclear waste **facilities,** chemical waste facilities, and chemical facilities.
- Preparation of safety analysis reports for U.S. Department of Energy **nuclear** and chemical facilities at the **Hanford** Site.

**Education**

M. S., Chemical Engineering, University of Washington
B. S., Chemical Engineering, Carnegie Mellon University

**Other**

Registered Professional Engineer, Washington

## John A. Piatt — Pacific Northwest Laboratory

Area of Responsibility

Industrial Hygiene, Hazard and Risk Analysis

Experience

22 years

- **Performed** risk and **safety** analyses for chemical operations in various U.S. Department of Energy facilities at the Hanford Site. Responsible for safety documentation of the new Pacific Northwest Laboratory Environmental and Molecular Sciences Laboratory.

- Developed an occupational health and safety program for the International Atomic Energy Agency Department of Safeguards.

- Senior Industrial Hygienist for PNL with a staff of 3,000.

- Regional Safety Manager **for** the U.S. Fish and Wildlife Service supporting managers of fish hatcheries and wildlife refuges in a six state region.

- System safety engineer at Headquarters, U.S. Army Test and Evaluation Command, and at two proving grounds. Supported safety test design and evaluation. Responsible for the resolution of technical occupational safety and health issues at the proving grounds.

Education

M. E., Industrial Engineering (System Safety), Texas A&M University, 1974
B. S., Industrial Engineering, University of Washington, 1971
B. S., Mechanical Engineering, University of Washington, 1971

**Other**

Certified Safety Professional
Certified Industrial Hygienist
Professional Engineer in Safety Engineering in the State of California

**Jay E. Rude** Westinghouse Hanford Company

Area **of** Responsibility

Hazard Analysis, Process Engineer

**Experience**

**23 years**

- Plant Engineer in the 300-Area Utilities and **Effluent** Treatment Plant, leading efforts in domestic and process sewer upgrades, installation of **filter** backwash pond and outfall, construction of filter plant chlorine storage facility, installation of new chlorinators and of treated **effluent** disposal system, replacement of ash sluice pond, and **installation** of metering manhole for the process sewer.

- Waste Water Plant Superintendent **for** Industrial and Domestic Treatment Plant of the City of Presser, Washington, including maintenance and operation of spray field and sewer system. Designed reviews of new filtration plant and waste water plant upgrade.

- Chief operator for the water treatment plant for the City of **Yakima,** Washington, including supervision of **influent,** grit, and rag removal; primary clarification centrifuge; primary and secondary digesters; trickling filters; activated sludge final clarification; chlorination; and spray field **for** industrial wastes.

- Operator and maintenance employee **for** the watershed of the City of The **Dalles,** Oregon, Waste Water Treatment Plant and Filter Plant. Participated in waste water plant construction, startup, and operation.

**Education**

Domestic and industrial waste water treatment training, Lim Benton Community College
Work-related **classes** at Columbia Basin College

**Other**

State of Washington Group IV Waste Water Treatment Process Operator
State of Washington Group II Waste Water Treatment Process Operator